Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Copyright, 1941, by Federation of Sewage Works Associations

Vol. XIII May, 1941 No. 3

Sewage Research:

Grease in Sewage, Sludge and Scum. I. Determination of Total and Non-Saponifiable Grease. By Harry W. Gehm and Eugene H. Trubnick 467

Corrections 484

Investigation of Methods for the Determination of Grease in Sewage and Sludge. By D. Okun, E. Hurwitz and F. W. Mohlman 485

Comparative Digestibility of Scum and Sediment Obtained From Primary Tank Sludge. By C. E. Keefer 492

Hydrogen Sulfide in Sewage. By Richard Pomeroy 498

Plant Operation:

Mechanical Flocculation and Bioflocculation of Sewage. By H. Heukelekian 506

Public Relations in the Construction and Administration of Sewage Works. By C. L. Velzy 523

Observations on Operation of the Activated Sludge Plant at Marlboro, N. J. By G. M. Ridenour 529

Stream Pollution:

Dissolved Oxygen and B.O.D. Determinations. Their Application and Interpretation. By C. C. Ruchhoft 542

A Method for Computing the Oxygen Curve in a Polluted Stream, With Special Reference to the Oxygen Consumption by Sludge Deposits. By Victor Jansa and Gunnar Åkerlindh 551

A Nomograph for Dissolved Oxygen Saturation in Water. By W. D. Hatfield 557

Long-Time Biochemical Oxygen Demands at Low Temperatures. By Edward W. Moore 561

The Operator's Corner:

An Open Letter to O. P. Rator 578

Electrical Equipment Maintenance 579

Interesting Extracts from Operation Reports 587

Day by Day with O. P. Rator 599

Three Reasons for Reliable Laboratory Data at Aurora, Illinois 601

The Maintenance of Sewage Treatment Works Equipment. By L. S. Kraus 603

Buffalo's Laboratory Motto 611

Editorial:

Save Our Streams 613

Proceedings of Local Associations:

Sewage Division Texas Section, S. W. W. A. 615
Kansas Water and Sewage Works Association 618
Arizona Sewage and Water Works Association 620
New England Sewage Works Association 622

Reviews and Abstracts:

Some Experiments on Precipitation of a Trade Waste Sewage. By C. Lumb and J. P. Barnes 624
Wet Milling of Corn. Recovery and Utilization of Process Losses. By A. L. Pulfrey, Ralph W. Kerr and H. R. Reintjes 624
Utilization of Waste Products. Recovery Processes: Salvage in the Chemical Industry 625
Waste Sulfite Liquor-Sewage Mixtures. Activated Sludge Treatment. By C. N. Sawyer 625
Biochemical Oxidation in Acid Water Containing Sewage. By C. C. Ruchhoft, M. B. Ettinger and W. W. Walker 626
Determination of Biochemical Oxygen Demand and Dissolved Oxygen of River Mud Suspensions. By C. C. Ruchhoft and Allen Moore 626
Hespeler's New Sewage Treatment Works. By W. B. Redfern 627
Certification in Ontario Being Favorably Received. By A. E. Berry 628
Barrie Sewerage Works. By G. Graham Reid 629
Determination of the Performance of the Kessener Units. By Dennis Dickinson ... 630
Experiments on the Manurial Value of Sewage Sludge from Septic Tanks. By H. T. Cranfield 631
The System Activated Sludge-Oxygenated Water. Part V. Changes in Oxidation-Reduction Potential Within the Sludge Floc. By Dennis Dickinson 632
Biochemical Studies on the Purification Mechanism of Activated Sludge. By Masazo Watanabe 633

Second Annual Convention Federation of Sewage Works Associations 636

Sewage Research

GREASE IN SEWAGE, SLUDGE AND SCUM*

I. DETERMINATION OF TOTAL AND NON-SAPONIFIABLE GREASE

By Harry W. Gehm and Eugene H. Trubnick

Associate and Assistant, Dept. Water and Sewage Research, New Brunswick, N. J.

Progress in grease removal suffers from the lack of satisfactory and standardized determination of grease in sewage, sludge and scum. If progress is to be made reasonably accurate means of determining the quantities of grease removed must be available. Analytical methods should produce comparable results when used by different investigators. At present several different methods are in use with rather scant information available on variations in results. The information has been adequately reviewed and the shortcomings of various methods have been pointed out (1) (2) (3).

A. Total Fat

In determining total fats on a sample of sludge or scum several factors must be considered. They are principally: pre-treatment of sample, type of solvent, character of extractor and time of extraction. This paper discusses each of these factors and intends to show how and why each of the factors was chosen and included in the method described.

1. *Pretreatment of Sample.*--Total grease determinations should include the grease present as soaps. It is well known that soaps, particularly of the alkaline-earth variety, are not completely extracted by the common solvents, such as ethyl ether, petrolic ether, and chloroform. It appears, therefore, advisable that an acid be used for conversion of the soaps to fatty acids. The acid commonly used for this purpose is hydrochloric acid. This acid is admirably suited to the purpose, because any excess remaining after reaction is readily volatilized. The possible drawback of such treatment is volatilization of some of the fatty acids upon drying of the sample which must be done to eliminate moisture prior to extraction. It is probable that the amount of fatty acids lost is low since the boiling point of the lowest fatty acid, namely formic acid, is higher than the drying temperature (100° C.) used. Moreover, the percentage of the lower acids (formic and acetic)

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

Note: Part of work was conducted with W. P. A. aid. Project Number 65-1-22-477.

in sludge is generally low. The boiling points of the higher fatty acids are all above 140° C. and their loss on drying may be considered negligible.

The complete removal of the sample from the dish in which it is dried is important. Dishes used for drying must have a smooth glazed interior. Porcelain dishes are in general more satisfactory than silica dishes having irregular surfaces. Pyrex and Vicor dishes are well suited for this purpose.

It is common practice to add an inert material, such as sand, to the sludge to facilitate its removal from the dish after drying. Experiments in which sand, powdered silica and diatomaceous earth were added to samples showed clearly that diatomaceous earth is far superior to other inert materials. Its superiority is due to its lightness. This material remains suspended in the sample during drying, depositing itself on the dish thoroughly dispersed with the sludge rather than as a separate bottom layer. Samples dried in this manner are readily scraped from the dish and leave no ring of grease on the side above the remainder of the sample. The resultant dispersion also allows better penetration of the sample by the solvent on extraction. The amounts found necessary to allow ready removal of sample are as follows:

Fresh Solids: Diatomaceous earth equivalent to weight of dry solids.
Scum: Diatomaceous earth equivalent to twice the weight of dry solids.
Ripe Sludges, Activated, Humus Tank: Diatomaceous earth equivalent to one-half the dry solids content.

The purified filter-aid type of diatomaceous earth is very well suited to this purpose.

2. *The Solvent.*—Ethyl ether, petrolic ether and chloroform are the most common solvents used for this purpose. No solvent can be expected to remove lipoidal materials completely and exclusively as sewage sludges contain such a wide variety of substances. Thus the ideal solvent for this purpose is one which will extract the most lipoidal material with a minimum of other substances. Such a solvent should not be chosen on the basis of analysis of sludge from sewage containing industrial waste of a fatty nature, but from domestic sewage sludge. The problem of the solvent is sufficiently complicated at present without further confusing it by applying an unsuited method to special problems. Petroleum wastes, wool scouring wastes and others can be analyzed by suitable methods and where they make up an important part of the sewage flow special consideration must be given to determining the solvent best suited to the work.

The fact that high values are invariably obtained when chloroform is the extractant has led to its use by many investigators. Chloroform has the added advantage of being non-inflammable. It was found, however, that some of the material extracted by chloroform was not lipoidal in character but a tarry acidic substance containing an appreciable percentage of nitrogen. The inclusion of this substance accounts to a large extent for the high results obtained.

Ethyl and petrolic ethers give higher results than most other solvents without extracting nitrogenous materials. In the analysis of most sludge samples ethyl ether gives somewhat higher results than petrolic. However, the difference in the case of domestic sewage sludges is not great if a long extraction time is allowed. The reason for differences and the necessity for long extraction may be explained by the fact that some fats are more soluble in one solvent than in the other. Petrolic hydrocarbons dissolve more readily in petrolic ether, while asphaltic materials, cholesterol and some of the harder waxes dissolve more quickly and possibly more completely in ethyl ether. Resins dissolve readily in ethyl ether but not in petrolic ether. Resins are not lipoidal in character and a solvent that does not dissolve them should be used. With this in view, petrolic ether is preferable to ethyl ether. Extraction for sixteen hours will remove most of the material difficultly soluble in either solvent, as will be shown in the recovery of cholesterol on extraction with petrolic ether. Most of the common animal and vegetable fats dissolve rapidly and completely in these solvents.

Petrolic ether has the drawback of being a hydrocarbon mixture containing fractions boiling at from 40° to 60° C. This is not serious if a proper extraction apparatus is employed. The ability of this solvent to dissolve petrolic hydrocarbons more readily than ethyl ether has influenced our choice of petrolic ether as the best solvent for our purpose. It fits in well in the determination of non-saponifiable fats, a large portion of which is composed of petrolic base motor oils finding their way into the sewage through street wash and garage and machine shop washing and waste. The satisfactory results obtained by several investigators using this solvent have also influenced our decision.

3. *Extraction Apparatus.*—Three common types of extractors have been tried. The Knorr, Soxhlet and Underwriters apparatus were put on trial with a number of samples. The Knorr apparatus works perfectly with ethyl ether and appears to give better exchange between the solvent and the sample than do the other two types. However, difficulties were immediately experienced with the Knorr apparatus due to fractionation of the petrolic ether. Boiling occurred in the sample tube thus entraining the solvent at that point and preventing circulation.

The Underwriters' device was also unsatisfactory as it allowed the lower boiling fractions to escape due to lack of condensing area. If the temperature of the heater was reduced to circumvent this difficulty only the lower fractions circulated.

The Soxhlet apparatus was by far the best of the three types tried. Whatman extraction shells were employed for holding the samples. Other types such as alundum and sintered glass either plugged, preventing circulation of the solvent, or allowed fine particles to pass through. All joints were of the interchangeable ground glass type. It is recommended that the condenser water jacket be of the Allihn or similar type and be two feet in length. No more than six condensers should be hooked in series to the cooling water supply. These precau-

tions prevent loss of solvent. Thermostatically controlled hot plates are ideal heating units as the proper rate of solvent circulation can readily be obtained with them. A diagram of the preferred apparatus is given in Fig. 1.

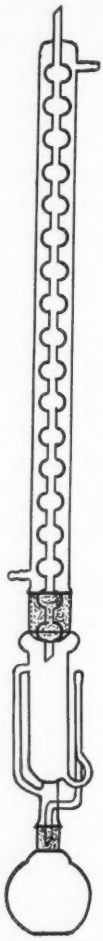


FIG. 1.—Type of extractor used.

4. *Time of Extraction.*—No set time of extraction is in general practice but most investigators employ a period of at least eight hours. Experiments were made to determine the period necessary using petrolic ether and the Soxhlet extractor, described above.

One sample each of fresh solids, ripe sludge, and sewage scum was extracted with petrolic ether in triplicate, for four, eight, twelve and sixteen hours respectively, after pre-treatment. After every four hours

of extraction, the excess ether was driven off, and the extracted grease in the extraction bottle was weighed.

The results, as shown in Fig. 2, indicate that extraction for 16 hours is required for complete removal of the fats and greases. In 12 hours,

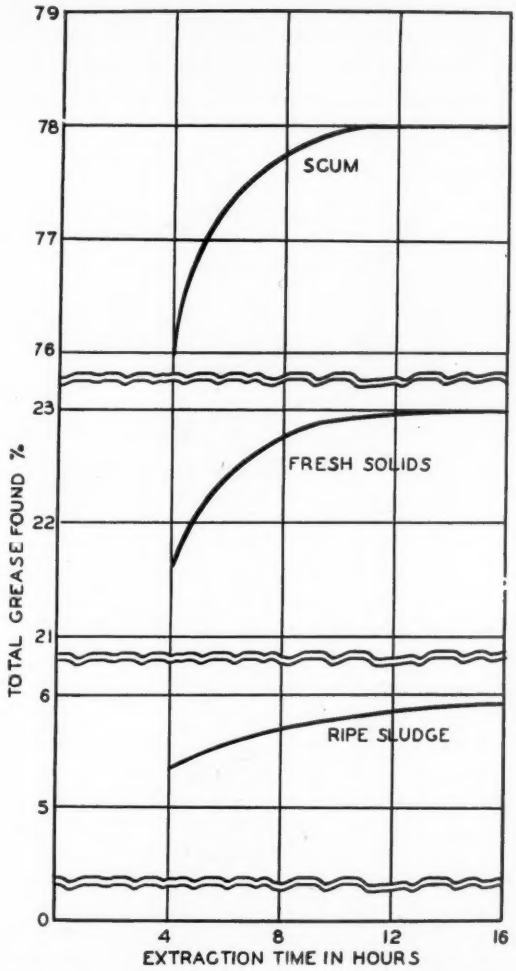


FIG. 2.—Effect of time on extraction on the recovery of total grease from sludges.

however, the extraction is practically completed, and extraction for four hours more does not indicate an appreciable increase in the amount of fat extracted.

METHOD

The solids content of the sludge or scum to be analyzed is first determined. A wet sample is then weighed in a tared porcelain dish

of about 50 ml. capacity. The sample taken for fresh solids should contain approximately 1 gram; ripe, activated and humus tank sludges 3 grams; and scum 0.5 gram of dry solids. Activated sludges of low solids content can be concentrated by centrifuging at 1000 to 2000 r.p.m. for 10 minutes or longer.

When the solids content is known, the dry solids in the sample taken can be calculated. Ten ml. of ten per cent (by volume) hydrochloric acid is then added, followed by the required amount of diatomaceous earth. For fresh solids a weight of the earth equal to the dry solids

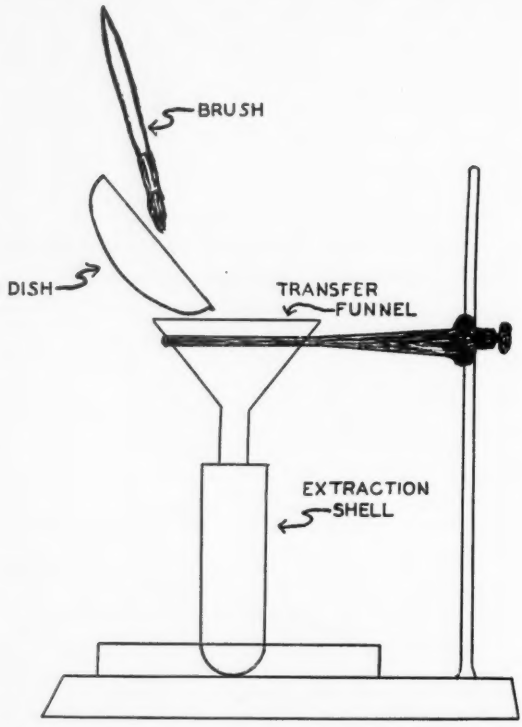


FIG. 3.—Method of transfer of sample to extraction shell.

in the sample is added, for ripe activated and humus tank sludge one-half the weight and for scum twice the weight. The mixture is stirred until uniform. The particles adhering to the stirring rod are washed into the dish with distilled water on removal. The dish is then placed on a steam bath and the contents are evaporated to dryness. The dried material is scraped from the dish with a spatula and transferred without loss to a Whatman extraction shell (a convenient size is the 26 by 60 mm.). The dish is finally brushed free of sludge particles and if any material remains it is taken up with filter paper moistened with petrolic ether. The paper used for cleaning is placed in the extraction shell with the sample. The method of transfer used is illustrated in Fig. 3.

The shell is then closed by folding over the top and fastening with a paper clip or by introducing a glass plug into the open end of the shell and securing with a band of copper wire around the outside of the shell. The shell with the opening upward is placed in the extractor, the flask of which has been previously weighed. When the apparatus is assembled petrolic ether is introduced through a funnel inserted in the top of the condenser. Sufficient solvent is introduced to cause the extractor to siphon over, and then about twenty ml. in excess added. Heat is applied and extraction is allowed to continue for 12 hours.

When extraction is completed almost all of the solvent is distilled from the flask, the grease is dried in an oven at 60° C. for eight hours, cooled in a desiccator and weighed. Calculation of grease in the sample: $\frac{\text{gms. increase}}{\text{gms. dry solids}} \times 100 = \text{per cent grease.}$

The increase in weight should be about 200 mgm. or more for accurate work. The sample weights suggested will give about the percentages shown in Table I.

TABLE I.—*Size of Samples for Analysis*

Type of Sample	Grams Dry Solids in Sample	Average Per Cent Grease	Mgm. Weighed
Fresh solids	1.0	25	200
Ripe sludge	3.0	8	240
Scum	0.5	50	250
Activated	3.0	8	240
Humus tank	5.0	5	250

To demonstrate the accuracy and consistency of analysis by this method a series of results on triplicate samples of twenty-six sludges of varied character is given in Table II. Examination of these data reveals that in the case of most samples the variation in percentage grease between any two of the three analyses made was within 0.2 per cent of each other. The largest difference noted between any two samples was 0.8 per cent, in the case of Bernardsville fresh solids. This amounts to 4.1 per cent error based on the average of the three analyses.

Additional results of similar nature are presented in Table III. Thirteen ripe sludges obtained from different parts of the country were analyzed in triplicate by this method. The consistency of the results is evident on inspection of the table. In almost every case the percentage grease found by analysis was within $\pm$ 0.1 of the average triplicate analyses on each of three different samples from two sources. These results were obtained with both fresh solids and ripe sludge. The data presented in Table IV again show the consistency between analyses. Variations in grease content present in samples obtained from the same source at different times can be expected. The variations between different samples from the same source will be discussed in a future paper of this series.

TABLE II.—*Results of Analyses of Samples for Total Grease by Method Presented*

Plant	Type of Sludge	Grease in Sludge, Per Cent of Dry Matter			Average
		1	2	3	
Hillsdale	Fresh Solids	16.9	16.4	16.9	16.7
	Ripe Sludge	9.6	9.5	9.8	9.6
	Activated	5.8	5.5	5.8	5.7
Bernardsville	Fresh Solids	19.8	19.0	19.4	19.4
	Ripe Sludge	9.5	9.3	9.5	9.4
	Activated	5.3	5.3	5.3	5.3
Madison-Chatham	Fresh Solids	22.7	22.3	22.9	22.6
	Ripe Sludge	5.3	5.3	5.2	5.3
	Activated	6.1	6.0	6.1	6.1
Morristown	Fresh Solids	25.3	25.5	24.8	25.2
	Ripe Sludge	4.1	4.0	4.1	4.1
	Activated	5.9	5.9	5.7	5.8
Plainfield	Fresh Solids	33.6	33.2	33.5	33.4
	Ripe Sludge	7.2	7.2	7.1	7.2
	Humus Tank	12.1	12.0	12.0	12.0
Freehold	Fresh Solids	25.8	25.8	25.4	25.7
	Ripe Sludge	7.1	7.1	7.2	7.1
	Humus Tank	11.4	11.6	11.4	11.5
Highland Park	Fresh Solids	22.6	22.3	22.4	22.4
	Ripe Sludge	6.3	6.4	6.3	6.3
New Brunswick	Fresh Solids	32.0	32.2	32.2	32.1
	Ripe Sludge	7.4	7.5	7.6	7.5
Elizabeth	Fresh Solids	25.2	25.4	25.2	25.3
South River	Scum	61.5	61.3	61.7	61.5
Rahway	Fresh Solids	18.8	18.6	18.5	18.6
	Ripe Sludge	7.5	7.6	7.7	7.6

B. NON-SAPONIFIABLE FAT

Particular interest is manifested in the non-saponifiable portions of the fats and greases in sewage sludge. Rudolfs (4) has shown that certain quantities of petroleum hydrocarbons hinder sludge digestion. With much garage and machine shop waste finding its way into sewerage systems, the presence of such petroleum derivatives becomes increasingly serious. To obtain information, prevent operation difficulties and if regulatory steps are to be taken, it becomes necessary to show precisely how much of such material is present in a sludge. The need arises, therefore, for an adequate method of analyzing for the non-saponifiables.

TABLE III.—*Analysis of Ripe Sludge Samples from Different Parts of the Country*

Source of Sample	Date Sampled	Per Cent Grease on Dry Matter Basis			
		1	2	3	Ave.
Rochester, N. Y.	Dec., 1927	6.4	6.3	6.4	6.4
Schenectady, N. Y.	Dec., 1927	4.3	4.0	4.3	4.2
Chambersburg, Pa.	Dec., 1927	6.3	6.3	6.5	6.4
Antigo, Wisc.	Jan., 1928	5.4	5.3	5.3	5.3
Marion, Ohio	Dec., 1927	8.6	8.6	8.6	8.6
Calumet, Ill.	Dec., 1927	4.0	4.2	4.1	4.1
Worcester, Mass.	Jan., 1928	14.3	14.0	13.9	14.1
Trenton, N. J.	Oct., 1937	2.0	2.0	2.1	2.0
Ft. Worth, Tex.	Jan., 1928	3.9	4.0	4.0	4.0
Mt. Alto, W. Va.	Dec., 1927	3.5	3.5	3.3	3.4
Lebanon, Pa.	Dec., 1927	16.9	16.5	17.0	16.8
Plainfield, N. J.	Nov., 1927	10.1	10.3	10.1	10.2
Baltimore, Md.	Nov., 1927	5.3	5.4	5.3	5.3

The absence of uniformity and standardization in the determination of non-saponifiable fats in sewage sludges is even more pronounced than in the case of total fat determinations.

In addition to the factors involved in total fat determinations, we are confronted with the variability of the time of saponification, the nature and concentration of alkali used for saponification, and the method of separating the saponified from the unsaponified material.

TABLE IV.—*Results on Three Samples Taken at Different Times from the Same Source*

Fresh Solids

Source of Sample	Date Sampled	Per Cent Grease Dry Matter Basis			
		1	2	3	Ave.
Elizabeth	Sept., 1938	29.5	30.1	29.9	29.8
Elizabeth	July, 1939	25.2	25.4	25.2	25.3
Elizabeth	March, 1940	22.4	22.3	23.0	22.6
Plainfield	July, 1939	28.0	27.2	27.8	27.7
Plainfield	Oct., 1939	26.8	26.7	26.3	26.6
Plainfield	Dec., 1940	33.6	33.2	33.5	33.4

Ripe Sludge

		1	2	3	Ave.
Plainfield	Nov., 1927	10.1	10.3	10.1	10.2
Plainfield	Sept., 1938	7.2	7.2	7.1	7.2
Plainfield	May, 1940	6.2	6.2	6.2	6.2
Freehold	Dec., 1937	7.1	7.1	7.2	7.1
Freehold	Oct., 1939	6.9	6.7	6.9	6.8
Freehold	June, 1940	6.8	6.8	6.8	6.8

Even with some of the existing methods, it is difficult to achieve accurate and reproducible results. As an example, Table V shows the wide variance of results achieved by analyzing each of various sludges in triplicate, using one of the existing methods.

Studies were conducted to develop a suitable standardized method for the determination of non-saponifiable fat in sewage sludges, which would eliminate as far as possible inherent variables, give reproducible results, and have a great degree of accuracy.

1. *Saponification in the Cold.*—An attempt was made to saponify the sludge fats with cold NaOH. Samples of sludge were allowed to stand for as long as seven days in contact with NaOH solutions of as high concentration as 25 per cent. Complete saponification could not be achieved. Even U.S.P. stearic acid, an easily saponified fat, was only 91 per cent saponified after seven days' contact with 25 per cent NaOH. Therefore, cold saponification was abandoned.

TABLE V.—*Old Method for Unsaponifiable Fats on Triplicate Samples*

Source of Sludge....	Unsaponifiable Fat—Per Cent of Dry Solids									
	Plainfield		New Brunswick		Freehold		Highland Park		Rahway	
Type of Sludge....	F.S.	R.S.	F.S.	R.S.	F.S.	R.S.	F.S.	R.S.	F.S.	R.S.
Trial No.										
1	4.7	5.4	7.2	6.2	4.7	2.2	5.9	4.6	6.6	2.2
2	6.6	4.5	5.5	5.0	5.3	4.3	6.2	4.1	4.1	3.3
3	5.3	4.9	6.4	5.7	6.1	3.9	5.0	5.8	7.1	2.8
Average	5.5	4.9	6.4	5.6	5.4	3.5	5.7	4.8	5.9	2.8

2. *Saponification with Heat.—A. General.* Determination of non-saponifiable fats in foods, soaps, and other fat-containing substances is often carried out with weak alkali solutions, of the order of 0.5 to 10 per cent NaOH or KOH. Such weak alkali concentrations were found to be too dilute and to contain insufficient caustic for complete reaction with the saponifiables of sewage sludge, because of the presence in the sludge of large amounts of other substances which react with sodium hydroxide. This inadequacy of the lower alkali concentrations is shown in Fig. 4.

Lang (5) has found that an aqueous alkali solution is just as accurate as alcoholic alkali in the determination of the saponification number. Alcoholic alkali solutions are time-consuming to prepare, and, because of instability, must be frequently re-standardized or freshly made. Then too, some fats are slightly soluble in alcohol. For these reasons aqueous sodium hydroxide solutions were used for saponification.

Samples were pre-treated in the manner outlined for the determination of total fat.

b. Pure Substances. Taylor (6) classifies as non-saponifiable fatty material the following groups of compounds: hydrocarbons, sterols, and wax alcohols.

Two of these three groups are commonly found in sewage—sterols from domestic wastes, and hydrocarbons in the form of oil and grease wastes, from garages and machine shops.

For our study, cholesterol was chosen as a typical sterol, and a purely petrolic motor oil as a typical hydrocarbon.

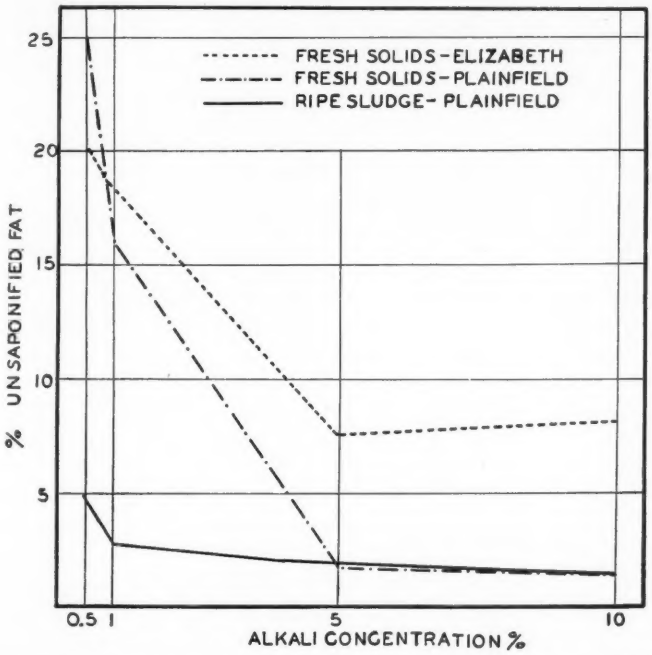


FIG. 4.—Effect of weak alkali solutions on the determination of non-saponifiable fats.

Samples of each of these materials were pre-treated as described above, and were submitted to treatment as follows:

Boiled with NaOH solution under reflux; filtered and washed; residue transferred to evaporating dish, acidified with 10 c.c. of 10 per cent HCl, and dried on water bath; contents of dish transferred to Soxhlet apparatus and extracted as described under total fat determination.

This treatment yielded practically complete recovery of the non-saponifiable fat from the residue on the filter. The results are shown in Table VI. However, when each of these substances was submitted to the same treatment in the presence of stearic acid, a saponifiable fat, very poor recoveries resulted, as is shown in Table VII. The soap formed from the stearic acid apparently acted as an emulsifying agent, carrying some of the non-saponifiable material through the filter. The

TABLE VI.—*Recovery of Cholesterol and Motor Oil After Heating With Alkali*

Trial No.	Weight Fat Sample, Mgm.	Weight Fat Recovery, Mgm.	Per Cent Recovery	Treatment
a. Cholesterol				
1	504	489	96.9	5 hrs. heat 20 per cent alkali
2	502	472	93.9	5 hrs. heat 20 per cent alkali
3	500	501	100.1	3 hrs. heat 10 per cent alkali
4	500	502	100.4	3 hrs. heat 10 per cent alkali
5	500	499	99.9	3 hrs. heat 10 per cent alkali
6	500	500	100.0	3 hrs. heat 10 per cent alkali
Average recovery.....			98.5	
b. Motor oil				
1	483	477	98.8	5 hrs. heat 20 per cent alkali

method, therefore, was modified in order to remove the soaps from solution before filtration.

c. New Method. The modified method progresses as follows:

1. The sample (cholesterol or motor oil, stearic acid and diatomaceous earth) was boiled in a 500 c.c Erlenmeyer flask with 100 c.c. of aqueous 10 per cent NaOH solution for two hours under reflux. The refluxing was achieved by means of the apparatus shown in Fig. 5, rather than with the usual reflux condenser, since it was found that excessive foaming of the boiling liquid (with possible loss of sample), could be avoided in this manner.

TABLE VII.—*Recovery of Cholesterol and Motor Oil from Mixtures With Stearic Acid After Saponification (Without Precipitation of Soaps)*

Trial No.	Weight Stearic Acid, Mgm.	Weight Unsaponifiable, Mgm.	Weight Recovered, Mgm.	Per Cent Recovery
a. Cholesterol				
1	500	500	314	62.8
2	500	500	225	45.0
b. Motor oil				
1	500	484	253	52.3
2	500	520	198	38.1

2. The excess alkali was neutralized with HCl to pH 7.5 to 8.5 and 25 c.c. of saturated $CaCl_2$ was added to precipitate the soaps.

3. This mixture was then filtered on a Buchner funnel under vacuum. Whatman No. 1 or another filter paper of similar quality was used. The paper was underlaid with filter cloth, to enhance filtration. The diatomaceous earth with which the original sample had been mixed acted as a filter aid, and greatly hastened the filtration. For further speeding up of filtration, the paper was pre-coated with an additional thin layer of diatomaceous earth.

4. The residue on the filter was thoroughly washed with hot water (about 70° C.), until the filtrate was free of chlorides.

5. The residue and filter paper were transferred to an evaporating dish and dried on a water bath.

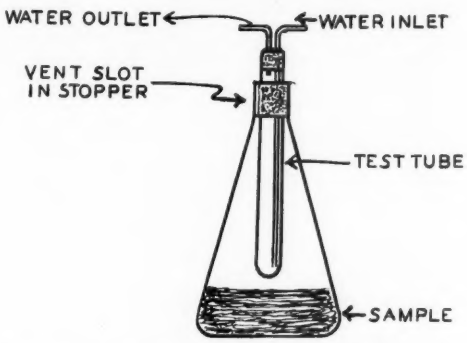


FIG. 5.—Reflux apparatus for saponifying samples.

6. The contents of the dish were transferred without loss, as with total fat determination, to an extraction thimble, and extraction was carried on as described.

The results, as shown in Tables VIII and IX, indicate an average of 97.8 per cent recovery of cholesterol, and 94.9 per cent recovery of motor oil with average deviations of 0.6 and 1.5 per cent, respectively.

TABLE VIII.—*Recovery of Cholesterol from Cholesterol-Stearic Acid Mixtures, After Saponification and Precipitation of Soap*

Trial No.	Weight Stearic Acid, Mgm.	Weight Cholesterol Added, Mgm.	Weight Cholesterol Recovered, Mgm.	Per Cent Recovery
1	250	250	247	98.8
2	250	250	244	97.6
3	500	500	492	98.4
4	500	500	489	97.8
5	500	500	482	96.4
		Average recovery.....		97.8

It is believed that the slightly lower results obtained with motor oil are due to the presence in the samples of small quantities of moisture and of saponifiable material.

3. *Applications of Methods to Sewage Sludge.—a. Time and Concentration.* In applying the method to analysis of sewage sludge, a study was made to determine the alkali concentration and time of saponification necessary for complete reaction. Various sludges were submitted to treatment with varying concentrations of NaOH (100 c.c. in each case) for one, two and three hours, respectively. After saponification,

TABLE IX.—*Recovery of Motor Oil from Motor Oil-Stearic Acid Mixtures After Saponification and Precipitation of Soap*

Trial No.	Weight of Stearic Acid, Mgm.	Weight Motor Oil Added, Mgm.	Weight Motor Oil Recovered, Mgm.	Per Cent Recovery
1	500	535	520	97.2
2	500	519	497	95.8
3	500	473	445	94.1
4	500	488	466	95.5
5	500	504	477	94.6
6	500	531	494	93.0
7	500	502	485	96.6
8	500	523	482	92.2
		Average recovery.....		94.9

the samples were neutralized, precipitated, filtered, and extracted as described. Typical results are shown in Table X.

With the sludges used, it was found that two hours heating with 10 per cent NaOH was the minimum treatment that would give complete saponification in all cases although with some of the sludges, the reaction appeared to be completed with less alkali or with a shorter treatment time. Two hours heating with 100 c.c. 10 per cent NaOH was therefore adapted as the standard procedure for the saponification reaction.

TABLE X.—*Effect of Time and Alkali Concentration on Saponification of Fats in Sludge and Scum*

Time Saponified, Hours	Unsaponified Fat—Per Cent of Dry Solids		
	With 5% Alkali	With 10% Alkali	With 15% Alkali
Ripe sludge—Freehold			
1	3.8	3.7	3.7
2	3.6	3.6	3.7
3	3.6	3.6	3.6
Fresh solids—Freehold			
1	3.4	2.5	2.7
2	2.6	2.5	2.5
3	2.5	2.4	2.5
Fresh solids—Elizabeth			
1	3 4	3.0	—
2	3.2	2.7	—
3	3.0	2.7	—
Scum—South River			
1	—	7.2	7.3
2	—	7.5	7.2
3	—	7.7	7.3

b. Time of Extraction. Fresh solids, ripe sludge and sewage scum were analyzed in triplicate for non-saponifiable grease. Each sample was extracted with petrolic ether for four, eight, twelve and sixteen hours, respectively. After every four hours of extraction, the excess ether was driven off, and the extracted grease was weighed.

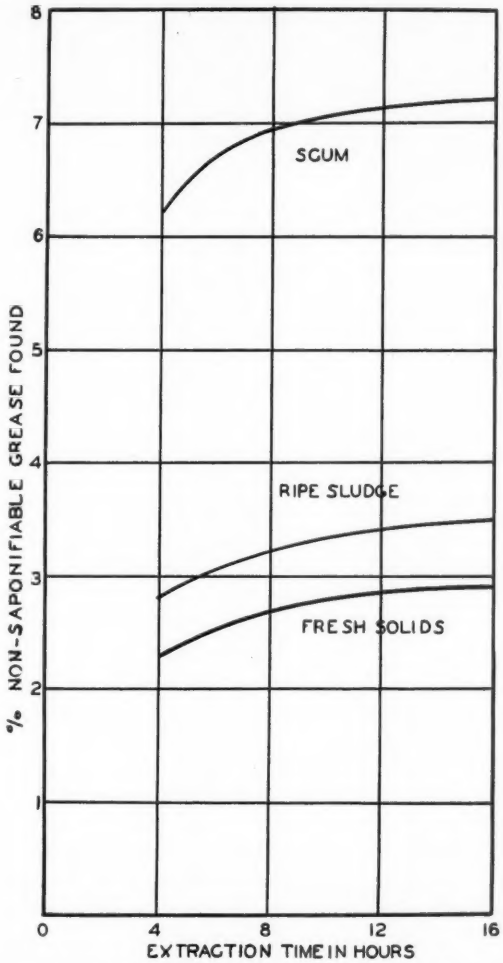


FIG. 6.—Effect of time of extraction on the recovery of non-saponifiable fats.

The results, shown in Fig. 6, indicate that, as is the case in the determination of total fat, extraction for 16 hours is necessary for complete removal of the fats and greases, but that practically complete recovery can be achieved in 12 hours.

c. Duplication of Results. In order to test the accuracy of the new method, and to determine the consistency of results achieved, aliquots of

thirteen different samples of sludge were analyzed for non-saponifiable fat by this method. The data, shown in Table XI, indicate a very close agreement between duplicate analyses of any individual sludge.

Discussion

Total Grease

In developing a method for determining total grease in sewage sludges several matters such as pre-treatment of sample, solvent, type of extractor and time of extraction must be considered. Of these the most difficult matter upon which to decide is the solvent best suited to the purpose. The decision to use petrolic ether was based on the experience of others as well as upon the results of numerous observations of the ability of the two most reliable solvents, namely ethyl and petrolic ethers, to dissolve lipoidal and non-lipoidal substances. As ethyl ether has demonstrated the property of dissolving resinous, non-lipoidal matter and is a poorer solvent of petrolic materials it was discarded in favor of the petrolic ether, despite its being a pure, uniformly boiling compound and a better solvent for some of the natural lipoids. The natural lipoids, such as cholesterol, however, are soluble in petrolic ether so that they are extracted practically completely.

As to the general method selected it might be well to state that shake-out methods from wet samples were tried and found to be unsatisfactory in that invariably the amount of grease extracted in this manner was decidedly less than that found by extraction of the dried sample, even when a known quantity of grease was added. This stands to reason when the types of grease present and the necessity of extracting the dry sample for twelve or more hours are considered.

The Soxhlet type of extractor is recommended in this paper as the best of the three tried. This does not mean that other types do not exist which may give as good or better results.

Judging from the results obtained on analysis of sludges the method presented is capable of giving consistent and reliable results on fresh solids, ripe sludge, activated sludge, humus tank sludge and scum. This particular method is probably not the ultimate in grease determinations, but its universal adoption, on its demonstrated merits, will produce uniformity of results which is now sadly lacking. The non-uniformity of results makes interpretation and comparison very difficult.

Non-Saponifiable Grease

The accuracy of the proposed method for the determination of non-saponifiable fat is attested by the practically complete recovery of cholesterol and of motor oil from mixtures of these materials with stearic acid. This complete recovery indicates that no serious loss of the unsaponifiable material occurs during filtration.

The data in Table II indicate a very high degree of consistency in results obtained on duplicates of the same sample. A comparison of these results with those obtained by an older unstandardized method, shows a very wide difference in consistency of results. The new method appears to be a decided improvement over what was achieved by the older methods.

In the case of sewage scum two hours heating with 10 per cent alkali did not indicate complete saponification. One hour heating, however, indicated complete reaction. This discrepancy is believed to be due to difficulty in sampling of a heterogeneous material like scum, rather than to a difference caused by the concentration of alkali used. The use of two hours heating with 10 per cent NaOH is therefore recommended for scum as well as for sludges.

TABLE XI.—*Duplication of Results with New Method for Non-Saponifiable Fat*

	Unsaponifiable Fat—Per Cent of Dry Solids												
Source of Sludge	Rahway		Bernardsville			Freehold			Eliza-beth	Highl'd Park	Hills-dale	Madison-Chatham	South River
Type of Sludge	F.S.	R.S.	F.S.	Act.S.	R.S.	Humus Tank	F.S.	R.S.	F.S.	F.S.	R.S.	R.S.	Scum
Trial No.													
1	2.9	1.6	2.5	2.2	3.4	3.2	2.5	3.7	2.6	2.9	2.3	2.5	7.1
2	2.9	1.7	2.3	2.1	3.4	3.2	2.5	3.6	2.7	3.1	2.5	2.7	7.3
3	3.0		2.6	2.2	3.1	3.2	2.6	3.6	2.7	2.9	2.2	2.6	7.4
4							2.4	3.7	2.8				
5							2.6	3.7	2.6				
6							2.3	3.6	2.7				
7							2.7		2.7				
8							2.5						
Average	2.9	1.65	2.5	2.2	3.3	3.2	2.5	3.65	2.7	3.0	2.3	2.6	7.3

Results might be reported in any of a number of ways: as per cent of total fat, per cent of volatile matter, per cent of wet sludge, or per cent of dry solids, but for the sake of uniformity, results should be expressed as per cent of dry solids.

In view of the presence of petroleum derivatives in the non-saponifiable fraction, petrolic ether is the most appropriate solvent for extraction. This solvent has the added advantage of not dissolving the calcium soaps, which are precipitated by the calcium chloride, nor dissolving resinous material present.

SUMMARY AND CONCLUSIONS

1. A method for the determination of total grease in various types of sewage sludges has been worked out, employing the best features of former methods.

2. The method was applied to numerous sludge samples with varying grease concentrations and from different sources giving consistent reproducible results.

3. A method has been developed for the determination of non-saponifiable fats in sewage sludges.

4. The method has been shown to be accurate with a sterol and a hydrocarbon motor oil.

5. The method gives consistent duplication of results with various sludges of different types.

REFERENCES

Knectges, Peterson and Strong, *This Jour.*, 6, 1083 (Nov., 1934).
Long, G., *Chemist-Analyst*, 2, 39 (1940).
Mahlie, W. S., *This Jour.*, 7, 527 (May, 1940).
Rawn, A. M., Banta, A. P., and Pomeroy, R., *Proc. A. S. C. E.*, 63, 1674 (1937).
Rudolfs, W., *This Jour.*, 9, 729 (1937).
Taylor, T. C., *Reactions and Symbols of Carbon Compounds*, 2nd Edition: 136, Century Co., N. Y. (1930).

CORRECTIONS

Dr. Hatfield notes the following corrections to be substituted in the table on page 144 of the January, 1941, issue, in the helpful data included "Under Your Glass Top":

1 yd. equals 0.304 meter—should be, 1 ft. equals 0.304 meter.
1 kg. equals 2.02 lb.—should be, 1 kg. equals 2.2 lb.
1 cu. yd. sand and/or gravel should weigh 2600 lb., not 1600 lb.

Dr. Levine has asked that the following correct statement be substituted for an ambiguous similar statement on page 141 of "Modern Sewage Disposal":

> On page 141 the first sentence in the last paragraph should read, "On the basis of the foregoing, aerobes might be considered as those organisms which produce catalase and generally contain cytochrome, but there are a number of exceptions to this simple differentiation."

INVESTIGATION OF METHODS FOR THE DETERMINATION OF GREASE IN SEWAGE AND SLUDGE *

By D. Okun, E. Hurwitz and F. W. Mohlman

Graduate Student, Armour Institute, Prin. San. Chem. and Dir. of Lab., The Sanitary District of Chicago

In the course of a study of the grease problems at the Southwest Treatment Works, a large number of grease determinations became necessary. The method recommended by the American Public Health Association (1) is very laborious. Large volumes of liquid must be evaporated to obtain quantities of grease large enough for accurate determination. Evaporation to dryness after acidification to hydrolyze the soaps also gives low results because of loss through steam distillation and resaponification of part of the fats by reaction with the concentrated metallic chlorides.

The search for a reliable method for grease determination led to comparisons of the procedure in Standard Methods (1), a wet extraction method suggested by Pomeroy (2) and a filtration method developed by the authors. During the period of investigation other methods, for the most part modifications of the filtration method, were suggested and tried.

Early Experiments.—The first tests with the wet extraction method indicated that complete removal of grease was not effected. The presence of water apparently inhibits solution of the grease in the solvent, particularly when the solids content is high. Wiley (3) states that "both with ether and petroleum ether the extraction process is greatly facilitated by the complete absence of water" and Ochi (4) has shown that the addition of water to soy beans reduces the extraction efficiency of ether. In the filtration method the sample was filtered through a specially prepared filter, dried, and extracted with the solvent in a Soxhlet extraction apparatus. A single layer of absorbent cotton, which had been washed with the solvent, was placed over a filter paper in a perforated aluminum dish. The aluminum dish was placed in a Buchner funnel and the sample filtered under vacuum. After filtration the cotton pad and filter paper containing the solids and greases were dried at 100° to 105° C. for 30 minutes to one hour, placed in a standard extraction thimble and extracted. The filtrate was shaken with solvent and the solvent with whatever grease it contained was added to the extraction flask through the thimble. In most cases, especially with sludges, the grease in the filtrate may be disregarded.

The apparatus described by Smith (5) modified to include the cotton pad, can be used conveniently. The cotton pad may be easily made by using the aluminum dish as a template.

* Contribution from the Graduate School of the Armour College of Engineering, Illinois Institute of Technology.

This method makes it possible to obtain checks on duplicate samples. Because of the hygroscopic nature of the extraction thimbles, weighing bottles are used to weigh the dried thimble and filter (paper and cotton) before filtration, and again after extraction. This procedure obviates the necessity for drying to constant weight between the filtration and extraction steps.

TABLE I.—*Grease Extraction from Sewage by the Filtration Method. All Samples Acidified.*

A. Sewage, Racine Avenue Pumping Station, 800 ml. samples.

	Drying Time, Minutes	Susp. Sol., Grams	Grease, Grams	Content, P.p.m.
Evaporation	—	—	0.888	1110
Filtration (residue)	15	1.105	0.890	1110
Filtration (residue)	30	1.138	0.917	1150
Filtration (residue)	60	1.128	0.895	1120
Filtration (residue)	90	1.153	0.918	1150
Filtration (residue)	120	1.149	0.904	1130
Filtrate:				
Wet extraction			0.006	8
Evaporation			0.008	10

B. Sewage, Racine Avenue Pumping Station, 800 ml. samples.

Evaporation	—	—	0.051	64
Filtration (residue)	10	0.109	0.045	56
Filtration (residue)	20	0.117	0.050	63
Filtration (residue)	60	—	0.053	66
Filtration (residue)	90	0.114	0.053	66
Filtrate:				
Wet Extraction (1)	—	—	0.0006	0.8
Wet Extraction (2)	—	—	0.033	41
Residue Extraction	—	—	0.020	25
Total	—	—	0.053	66

C. Sewage, Southwest Treatment Works, 1500 ml. samples.

Evaporation	—		0.0149	10.0
Evaporation	—		0.0187	12.4
Filtration (residue)	30		0.0331	22.1
Filtration (residue)	60		0.0368	24.5
Filtration (residue)	90		0.0345	23.0
Filtration (residue)	120		0.0332	22.1
Filtrate:				
Wet Extraction (1)			0.0004	
(2)			0.0016	
Average			0.0010	0.7
Evaporation (1)			0.0001	
(2)			0.0004	
Average			0.0003	0.2

TABLE I.—*Continued.*

D. Raw Sewage, Southwest Treatment Works, 1500 ml. samples.

	Drying Time, Minutes	Susp. Sol., Grams	Grease, Grams	Content, P.p.m.
Evaporation	—		0.0142	9.5
Evaporation	—		0.0175	11.6
Filtration (residue)	30		0.0262	17.5
Filtration (residue)	60		0.0254	16.9
Filtration (residue)	60		0.0268	17.8
Filtration (residue)	90		0.0245	16.4
Filtration (residue)	120		0.0228	15.2
Filtrate:				
Wet Extraction (1)			0.0004	
(2)			0.0008	
Average			0.0006	0.4
Evaporation (1)			0.0004	
(2)			0.0002	
Average			0.0003	0.2

E. Primary Tank Effluent, Southwest Treatment Works, 1500 ml. samples.

Evaporation	—	—	0.0025	1.7
Evaporation	—	—	0.0026	1.7
Filtration (residue)	30	0.0418	0.0053	3.5
Filtration (residue)	30	0.0430	0.0048	3.2
Filtration (residue)	60	0.0423	0.0052	3.5
Filtrate:				
Wet Extraction (1)			0.0001	
(2)			0.0001	
(3)			0.0001	
Average			0.0001	0.1

Comparative tests were run to test the reliability of the filtration method and to determine the time necessary for drying before extraction. The sample was screened, divided carefully into several 800 ml. or 1500 ml. portions and acidified with HCl. The samples for evaporation were taken down on a steam bath, weighed, transferred to an extraction thimble when dry, and extracted for 1.5 hours with petroleum ether. The remaining samples were filtered. All the filtrates were composited, and portions of the composite were extracted by wet extraction method and by evaporation and extraction. The residues were extracted after drying at 105° C. From 2 to 10 minutes were required for filtration of the samples, with an average time of about 5 minutes. The results of these tests are shown in Table I.

These results show consistently higher grease content by the filtration method than by evaporation and extraction of the residue. This was especially true for low concentration of grease. The grease passing through the filter amounted to approximately only 0.5 to 2 per cent

of the total grease in the sample. This grease is in dispersed form and is readily extracted by wet extraction. However, the amount of grease in the filtrate is so small that in most cases it may be disregarded without seriously affecting the accuracy of the determination. Errors in sampling will exceed those incurred in neglecting the filtrate. The residue should be dried about 30 minutes to prevent inhibiting extraction of grease by moisture.

Later Tests.—Further tests were made to afford a direct comparison of the filtration method with the standard evaporation method and wet extraction. Table II shows the results of this comparison.

TABLE II.—*Comparison of Grease Determination Procedures on Southwest Sewage. Results in P.P.M.*

Test No.	Standard Method	Wet Extraction	Filtration	Filtration $FeCl_3$ Modification
1	154	212	168	173
2	67	110	70	84
3	49	79	52	54
4	43	77	48	54
5	49	92	54	66

These results indicate a considerable loss by the Standard Method, and low results by the filtration methods, in which the filtrate was not extracted. Ignition of the extract by the wet method left no ash, therefore no salts were being extracted by the wet method. Appreciable amounts of grease were lost through steam distillation and re-saponification when the Standard Method was used. Also appreciable amounts of colloidal grease were lost through the filter by the filtration method. When the filtration method was modified by clarifying

TABLE III.—*Comparison of Grease Determination Procedures on a Synthetic Emulsion of Grease and Water. Results in P.P.M.*

Test No.	Standard Method	Wet Extraction	Filtration $FeCl_3$ Mod.	Filtration		
				By Plain Filtration	By Wet Extrac. from Filtrate	Total
1	147	232	212	180	56	236
2	151	212	192	170	32	202
3	139	201	171	160	43	203
4	175	225	187	166	47	213

the sample with $Fe(OH)_3$ floc (formed from $FeCl_3$) a slightly additional amount of grease was extracted. The theory of this treatment is that the floc might adsorb the colloidal grease particles and prevent them from passing through the filter. The treatment facilitated filtration, but did not result in recovery of much more grease.

These results were confirmed on a synthetic mixture made up of stearic and oleic acids, vaseline, lanolin and sodium oleate. The results are shown in Table III.

Further tests were made using preliminary solids, the results of which are recorded in Table IV.

TABLE IV.—*Comparison of Grease Determination Procedures on Preliminary Solids. Results in P.P.M.*

Test No.	Standard Method	Wet Extraction	Filtration	Filtration $FeCl_3$ Modification
1	684	552	676	688
2	352	167	345	370
3	274	162	245	256
4	346	233	416	424
5	207	200	208	209
6	390	246	388	400

The results of these tests are the reverse of those found with sewage. Wet extraction failed to remove the grease completely whereas filtration and the ferric chloride modification of the filtration method removed much larger quantities. The wet method fails to extract all of the grease from sludge because of the high concentration of insoluble solids in sludge, and the difficulty of intimate contact between the solvent and the solids.

Mr. A. M. Rawn, of Los Angeles, called our attention to a filtration method suggested by Mr. H. Ludwig of East Bay Cities Sewage Disposal Surveys, Berkeley, California. In this method the sample is acidified, then boiled to complete the hydrolysis, chilled in the refrigerator to congeal the free grease, and finally filtered. Combining the filtration method as described above with Mr. Ludwig's suggestion, comparisons were made with wet extraction on sewage and with the ferric chloride modification on preliminary solids. This was done because in the preliminary work already noted, wet extraction removed the greater amount of grease from sewage, whereas, the ferric chloride modification removed more from preliminary solids.

The results of these comparisons are shown in Table V.

TABLE V.—*Comparison of Grease Determination Procedures. Results in P.P.M.*

Test No.	Sewage		Preliminary Solids	
	Wet Extrac.	Filtration Chilling Mod.	Filtration $FeCl_3$ Mod.	Filtration Chilling Mod.
1	64	64	101	202
2	61	61	554	1083
3	53	53	255	478
4	58	59	145	258
5			155	235

This modification obviously eliminates any advantage which wet extraction had over filtration in grease determination of sewage. Also it became apparent that even though the $FeCl_3$ modification was an im-

provement over wet extraction or plain filtration it was not efficient in the removal of grease from preliminary solids. Results of extraction by the chilling modification were almost twice as great. This is due to the fact that more efficient hydrolysis is obtained by the lower pH to which the sample can be brought. Boiling tends to increase hydrolysis and chilling serves to congeal the grease so that it can be conveniently filtered.

Analyses to show that check results can be had by this method are shown in Table VI.

TABLE VI.—*Duplication of Results. Filtration Method, Chilling Modification. Results in P.P.M.*

	1	2	3	Average	Max. Variation from Average
Sewage	66	64	68	66	2
Preliminary Solids	236	243	238	239	4

Details of the modified filtration method are as follows:

Reagents:

Hydrochloric acid, conc.
Petroleum ether, b.p. 30°–60° C.
Cotton discs washed with solvent and dried
Filter paper
Buchner filter.

Procedure:

Strongly acidify sample in a beaker with HCl and boil for 10 to 15 minutes. Cool, and chill in refrigerator for at least two hours, preferably overnight.

Prepare a Buchner filter with a 9 cm. filter paper overlaid by a grease-free cotton disc (a perforated aluminum dish may be used in place of the Buchner funnel).

Filter the chilled sample through the cotton disc. Wipe the sides of the beaker dry with a pad of grease-free cotton, and add to the cotton disc in the filter.

Dry filter paper and cotton pads in the aluminum dish or in an evaporating dish, in the oven at 103°–105° C. for 30 to 45 minutes.

Remove filter paper and cotton pads, roll to fit suitable Soxhlet extraction thimble, and insert in thimbles. Extract for a minimum of two hours, preferably six.

The perforated aluminum dish described by Smith (*This Journal,* **6**, 908, Sept., 1934) is very convenient for this determination.

DISCUSSION OF METHODS

A comparison of these procedures for determination of grease in sewage and sludge leads to the following conclusions:

(*a*) The Standard Method gives low results.

(*b*) Wet extraction gives low results on sludge, but is satisfactory for sewage containing low concentrations of suspended solids.

(*c*) The filtration procedure, without wet extraction of the filtrate, gives low results. The ferric chloride modification gives slightly higher results.

(*d*) The filtration procedure when modified by preliminary boiling and chilling of the sample, as suggested by Ludwig, gives the most complete extraction and the most consistent results of all methods tried.

The same solvent, petroleum ether of b. p. 30° to 60° C. was used in all comparative tests.

Acknowledgment is made of the help of the personnel of the Sanitary District Main Laboratory and W.P.A. Projects 30,112 and 30,371 for much of the analytical work reported herein.

References

1. Standard Methods of Water Analysis, American Public Health Association.
2. Richard Pomeroy, personal communication.
3. H. W. Wiley, *Principles and Practice of Agricultural Analysis*, Volume III, p. 75.
4. S. Ochi, "Extraction Power of Carbon Tetrachloride for Fatty Oils," *J. Chem. Ind. Tokyo*, 22, 1066 (1919).
5. J. I. Smith, "Investigation of Rapid Methods for Sludge Solids Estimation," *This Journal*, 6, 908 (Sept., 1934).

COMPARATIVE DIGESTIBILITY OF SCUM AND SEDIMENT OBTAINED FROM PRIMARY TANK SLUDGE

By C. E. Keefer

Bureau of Sewers, Baltimore, Md.

When raw sludge from preliminary-sedimentation tanks is digested in separate sludge-digestion tanks, there is usually a segregation of the material into scum, sediment and an intermediate layer of sludge liquor. One question that naturally arises is the relative speed of digestion of the scum and the sediment. In order to throw some light on this problem a group of laboratory experiments was conducted at the Baltimore sewage works for a period of 43 days.

Experimental Procedure

A mixture of sludge having the analysis as shown in Table I and containing two parts by weight of raw volatile solids to one part of digested volatile solids was prepared. Before mixing the materials the pH of the raw sludge was raised from 5.0 to 6.5 by the addition of

Table I.—*Analyses of Raw and Digested Sludges*

	Solids		pH
	Total, Per Cent	Volatile, Per Cent	
Raw sludge			
Before addition of lime	9.27	77.97	5.0
After addition of lime	10.05	72.88	6.5
Digested sludge	9.23	57.59	7.0
Mixture (2 parts raw: 1 part digested)	9.48	65.04	6.6

lime. The material was then put into special containers and maintained at a temperature of 28° C. $\pm$ 1° C. in an incubator room. Four of the containers were fiber electric conduits, which were 4 in. in diameter and 30 in. long. Two of these were provided with bottoms and were used as controls. A one-quart ginger-ale bottle, from which the bottom had been removed, was attached to each of the other two. Rubber tubing was fitted on the neck of each bottle and was also connected with a two-neck Woulff bottle. Ten pounds of the sludge mixture was put into each of these four containers. Once a day except on Sunday any sediment which collected in the necks of the ginger-ale bottles was transferred through the rubber tubing into the Woulff bottles. Provision was made for separately collecting, measuring and analyzing the gas from the scum in the top of the fiber electric conduits and from the sediment in the Woulff bottles. In addition to using as controls the

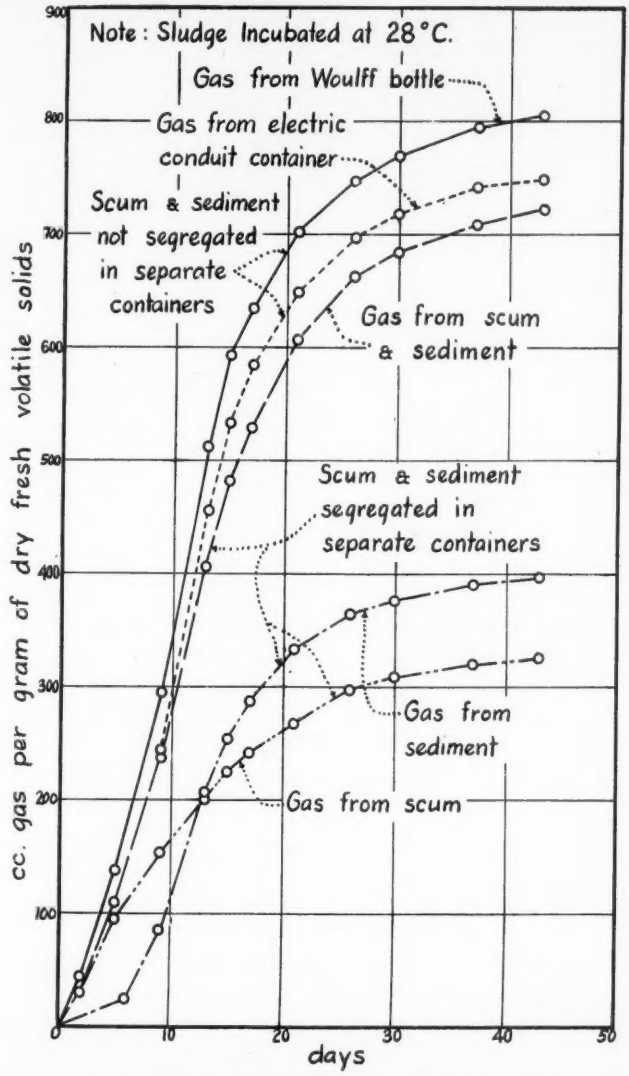


FIG. 1.—Total gas production from scum and sediment.

sludge in the two fiber conduits to which ginger-ale bottles were not attached sludge was also put into two additional Woulff bottles for control purposes. The quantity and the character of the gas that was produced were used to indicate the degree of sludge digestion.

RESULTS

The foregoing equipment permitted conducting the experiment in duplicate. The results of the two groups of tests were sufficiently

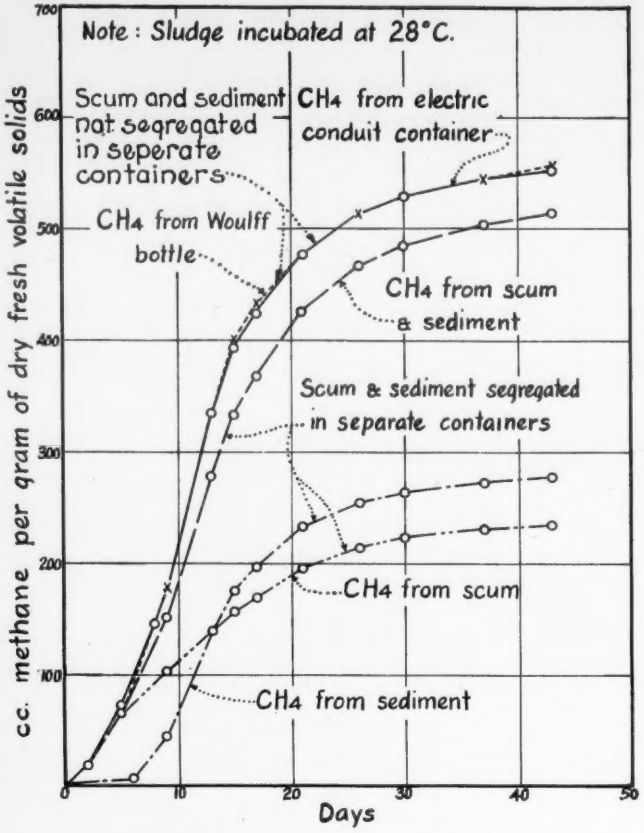

Note : Sludge incubated at 28°C.
Scum and sediment not segregated in seperate containers
CH4 from electric conduit container
CH4 from Woulff bottle
CH4 from scum & sediment
Scum & sediment segregated in separate containers
CH4 from scum
CH4 from sediment
cc. methane per gram of dry fresh volatile solids
Days

FIG 2.—CH_4 production from scum and sediment.

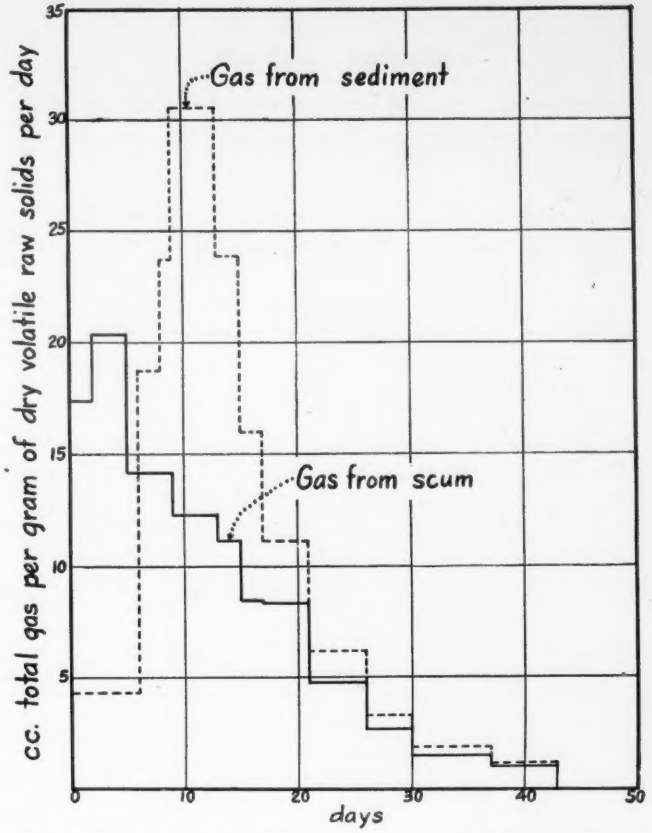


FIG. 3.—Daily production of total gas from scum and from sediment.

consistent that those of only one group are given. Figures 1 and 2 give the amount of total gas and methane from the various containers. The least amount of total gas was produced by the sludge that was separated in the container and in its attached Woulff bottle. The sediment produced 55 per cent of the total gas and the scum 45 per cent. Although the sludge in the two containers which served as controls and in which the scum and the sediment were not kept in separate containers produced more total gas and methane than the material that was segregated, this greater volume of gas was not sufficiently more to warrant formulating any reasons for the increase. The daily amounts

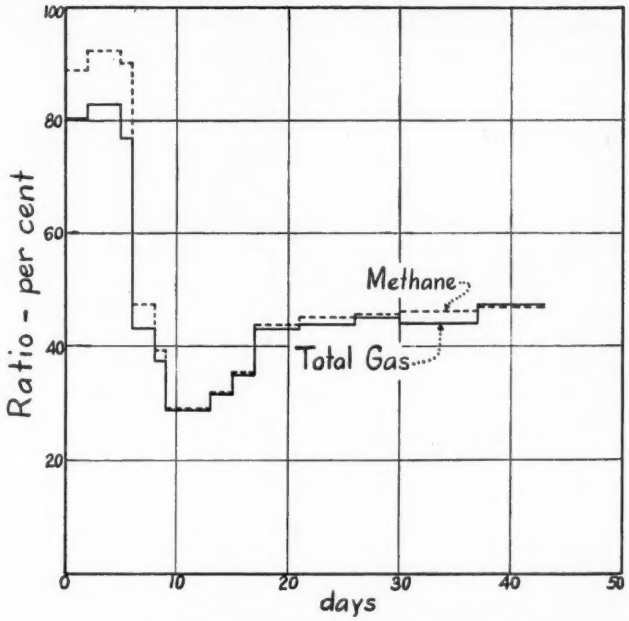


FIG. 4.—Ratio of gas from scum to gas from all of sludge.

of total gas per gram of dry volatile solids from the scum and from the sediment are shown in Fig. 3. The maximum gas production from the scum occurred between the second and the fifth day, after which the production decreased, and the peak production from the sediment took place between the ninth and the thirteenth day. Up to the sixth day (Fig. 4) the greater portion of the gas was coming from the scum, and from the ninth to the seventeenth day the scum was producing only about 30 to 35 per cent of the gas. After the seventeenth day the gas production from the scum varied from approximately 42 to 44 per cent of all of the gas. Figure 5 indicates the percentage of methane in the gas from the scum and from the sediment. Except for the last six days of the experiment there was a greater percentage of methane in the gas from the scum.

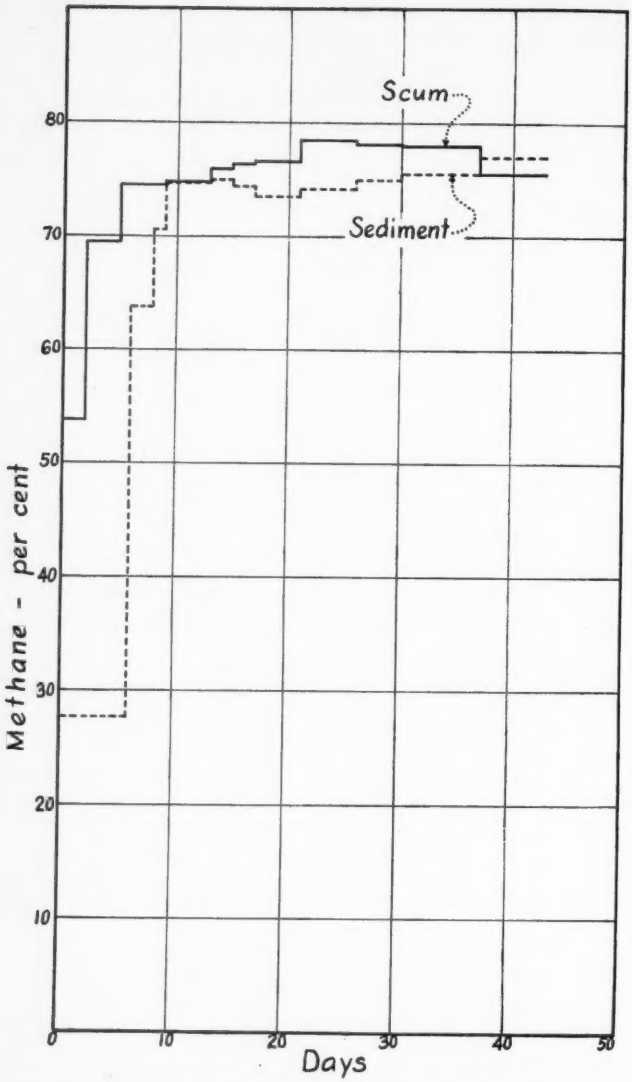


FIG. 5.—Percentage of CH_4 in gas from scum and from sediment.

Table II gives the analysis at the end of the experiment of the scum and the sediment that were kept in separate containers and also of the sludge that was not separated. The digested scum contained 54.66 per cent of volatile matter on the dry basis and the digested sediment 52.18 per cent. As was to be expected the solid content of the scum was much higher than of the sediment, being 13.75 per cent in the former and 5.25 per cent in the latter. The sludge that was not segregated into scum and sediment contained 52.41 per cent volatile matter on the dry basis,

an amount slightly less than the average volatile content of the sludge that had been segregated into scum and sediment.

TABLE II.—*Analysis of Sludge at End of 43-Day Digestion Period*

	Volatile Matter, Dry Basis, Per Cent	Solids, Per Cent
Sludge segregated		
Scum	54.66	13.75
Sediment	52.18	5.25
Sludge not segregated		
In electric conduit	52.41	6.94
In Woulff bottle	52.85	7.13

CONCLUSIONS

The following conclusions are tentative and may be subject to revision as the results of further experiments, using sludges from various sources, become available.

1. The daily segregation in separate containers of sediment from scum did not hasten digestion.

2. During the first six days of the digestion period the scum digested more rapidly than the sediment.

3. During the 43-day digestion period 45 per cent of the total gas and 46 per cent of the methane was produced by the scum. These results indicate that the scum digested almost as rapidly as the settled sludge.

4. The gas produced by the scum had in general a higher methane content than the gas produced by the settled sludge.

The Baltimore sewage works is under the general supervision of George Cobb, chief engineer, Department of Public Works and George E. Finck, sewerage engineer, with G. K. Armeling, superintendent. The analytical work was done by Herman Kratz, Jr., and J. W. Bushman, junior chemists.

HYDROGEN SULFIDE IN SEWAGE

By Richard Pomeroy *

A. The Ionization of Hydrogen Sulfide

Knowledge of the concentration of un-ionized hydrogen sulfide in sewage or water is highly important where sulfide nuisances are being encountered, since the rate of escape of sulfides to the atmosphere, other things being equal, is proportional to the H_2S concentration. The simplest method to determine this quantity depends upon measuring the pH and the dissolved sulfide concentration, and calculating from these quantities the amount of un-ionized H_2S. The accuracy of the result depends, among other things, on the accuracy of the value assumed for the ionization constant of hydrogen sulfide. This constant is not well known. The present article gives some further information on this point.

Between 1899 and 1904 various authors made determinations of the primary ionization constant of H_2S at 18° C., using the conductivity method, with results as shown in Table I.

Table I

Author	Constant	Reference
Th. Paul	1.2×10^{-7}	(1)
Walker and Cormack	0.57×10^{-7}	(2)
F. Auerbach	0.91×10^{-7}	(3)

The result of Auerbach has been generally accepted and has prevailed in the literature.

From Auerbach's result and a value of 6000 calories per mol for the heat effect attending the first-stage ionization of H_2S, Lewis and Randall calculated the constant at 25° C. to be 1.15×10^{-7} (4).

When the significance of the ionization of H_2S in sewage chemistry was pointed out by the author in 1935 (5) an experiment was cited in which the rate of evolution of sulfide from solution was shown to vary with the pH as expected on the basis of the accepted ionization constant. The experiment was crudely done merely for demonstration purposes, and an excellent agreement between observed and calculated results was considered fortuitous. It appeared, however, that the constant of 0.91×10^{-7}, due to Auerbach, was substantially correct, and on this basis a table of degrees of ionization at various pH values was published (5, 6).

In 1938 Epprecht (7) published a new determination of the constant, yielding the value 3.31×10^{-7} at 25° C.

Because of the wide discrepancy between Epprecht and Auerbach, some data were collected at the laboratory of the Los Angeles County Sanitation Districts to clarify the picture.

* Of Montgomery and Pomeroy, Pasadena, Calif.

Two experiments were conducted in a sewer by determining the maximum attainable concentration of H_2S in the atmosphere over the flowing sewage. These experiments had the advantage of eliminating any possible uncertainty in the transfer of ideal laboratory data to the desired calculation of possible H_2S concentrations in sewer atmospheres.

A bell jar formed by cutting the bottom from a 5-gallon bottle was cleaned and dried (to eliminate surface oxidation of H_2S) and hung in the stream of sewage. A pulley and counterweight provided the means to keep the jar at such height that atmospheric pressure was maintained within the jar. Samples of the air were withdrawn through zinc acetate solution and the sulfide determined colorimetrically. Dissolved sulfide and pH determinations were made on the sewage at frequent intervals. A suitable paddle provided mild agitation of the surface of the sewage.

Results were averaged over a suitable interval after the gas phase had apparently reached substantial equilibrium with the sewage. Using the known solubility of H_2S in water, it was possible to calculate the fraction of the dissolved sulfides in the form of un-ionized H_2S, and from this and the pH, the ionization constant. Results are shown in Table II.

TABLE II

Experiment	Temperature, °C.	Number of Gas Analyses	Average H_2S in Gas, P.p.m.	Calculated H_2S in Sewage, P.p.m.	Average Dissolved Sulfides in Sewage, P.p.m.	Average pH of Sewage	Apparent Ionization Constant
1	22.05	12	73.0	0.265	1.54	7.30	2.4×10^{-7}
2	23.3	9	83.5	0.294	1.175	7.17	2.0×10^{-7}

The determinations of pH were made colorimetrically in Experiment 1 and with the quinhydrone electrode in Experiment 2. The apparent ionization constants require correction, as shown subsequently.

One experiment was performed in the laboratory, in which five gallons of water were buffered with phosphates, and enough sodium sulfide added to give about 9 p.p.m. of sulfide. The amount of buffer used was sufficient so that the ionic strength of the solution was substantially the same as that of the sewage of the Sanitation Districts, namely 0.018. The pH was determined by a glass electrode to be 7.46.

A small stream of nitrogen was bubbled through the solution, using a fritted glass diffuser. The gas was then led through zinc acetate solution for a measured interval of time and the collected sulfide subsequently determined by titration, so that the rate of evolution of H_2S could be ascertained. The rate of removal of sulfide was kept so low that the change in concentration in the five-gallon bottle was insignificant. Four successive tests showed good agreement. Then, with no change in the rate of nitrogen flow, the solution was acidified and the rate of H_2S evolution again determined.

The initial rate was 17.47 per cent of the rate after acidification, indicating an apparent ionization constant of 1.64×10^{-7} at the temperature of the test, which was 22.0° C.

The apparent ionization constants were calculated by the formula:

$$\text{Log } K' = \log [HS^-] - \log [H_2S] - pH$$

in which $[HS^-]$ and $[H_2S]$ refer to the concentrations. If the effect of the ionic strength on the activities of ions be taken into account to secure the fundamental ionization constant, the equation takes the form:

$$\text{Log } K = \log [HS^-] - \log [H_2S] - pH - 0.5 \sqrt{\mu}$$

where μ is the ionic strength.

By applying this correction to the results of these experiments, and correcting these and the values secured by the other investigators to 25° C. to facilitate comparison, we get the values shown in Table III.

TABLE III

Author	Primary Ionization Constant of H_2S at 25°C.
Paul	1.52×10^{-7}
Walker and Cormack	0.72×10^{-7}
Auerbach	1.15×10^{-7}
Epprecht	3.31×10^{-7}
Pomeroy	2.2×10^{-7}
Pomeroy	1.8×10^{-7}
Pomeroy	1.55×10^{-7}
Weighted average	1.7×10^{-7}

Although the experiments reported herein are not of the maximum attainable accuracy, it is difficult to see where they could be in error as much as the discrepancy between them and the result of Epprecht. However, without attempting to ascertain whose result is most accurate, or to account for the divergence on the basis of some anomalous behavior of hydrogen sulfide, it may be noted that the experiments—especially the first two—provide a practical answer to the question of the amounts of H_2S in equilibrium with sewage under determinable conditions. In the absence of more adequate information it is suggested

TABLE IV.—*Hydrogen Sulfide Factors*

pH	Factor	pH	Factor	pH	Factor
5.0	0.98	6.7	0.50	7.9	0.059
5.2	0.97	6.8	0.44	8.0	0.048
5.4	0.95	6.9	0.39	8.2	0.031
5.6	0.93	7.0	0.33	8.4	0.020
5.8	0.89	7.1	0.28	8.6	0.012
6.0	0.83	7.2	0.24	8.8	0.0079
6.1	0.80	7.3	0.20	9.0	0.0050
6.2	0.76	7.4	0.17	9.2	0.0032
6.3	0.72	7.5	0.14	9.4	0.0020
6.4	0.67	7.6	0.11	9.6	0.0013
6.5	0.61	7.7	0.091	9.8	0.00079
6.6	0.56	7.8	0.073		

that tentative hydrogen sulfide factors be calculated on the basis of an ionization constant of 1.7×10^{-7}. For an ionic strength of 0.02, and at 25° C.—conditions which may be considered typical for sewers where sulfide difficulties are observed—the apparent constant becomes 2.0×10^{-7}. Ordinary deviations from this ionic strength and temperature will not seriously affect the results, but corrections may be applied if necessary.*

CORRECTION TO BE APPLIED TO ACTUAL MEASURED pH TO OBTAIN EFFECTIVE pH FOR USE IN TABLE IV

Ionic Strength	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.
0 (pure water)	−.29	−.22	−.14	−.07	0	+.08
0.01 (typical water supply)	−.24	−.17	−.09	−.02	+.05	+.13
0.02 (typical sewage)	−.22	−.15	−.07	0	+.07	+.15
0.10 (typical sludge liquor)	−.13	−.06	+.02	+.09	+.16	+.24
0.70 (sea water)	+.13	+.20	+.28	+.35	+.42	+.50

On the basis of a constant of 2.0×10^{-7} Table IV has been set up to give the factors by which the dissolved sulfide concentration must be multiplied to give the concentration of hydrogen sulfide (calculated as S).

The concentration of H_2S in an atmosphere in equilibrium with a sulfide-containing liquid may be found by multiplying the concentration in the liquid by a factor which varies with the temperature. Values of this factor for certain temperatures are shown in Table V.

TABLE V

Temperature, ° C.	Factor to Determine Equilibrium Concentration of H_2S in Atmosphere, in Parts per Million by Volume
16	248
18	262
20	286
22	291
24	307
26	323
28	339
30	356

SUMMARY

Determinations of the primary ionization constant of hydrogen sulfide gave values averaging 1.7×10^{-7} when corrected to 25° C. This is intermediate between the old value of Auerbach and the recent value of Epprecht.

* Increase of temperature has the same effect as an increase of pH to the extent of 0.0146 unit per degree. Increase of ionic strength has a similar effect, but amounting to one half the square root of the ionic strength. The table gives the magnitude of the correction for certain conditions.

ACKNOWLEDGMENT

The author wishes to thank Mr. Fred Bowlus of the Los Angeles County Sanitation Districts, and the field survey party under his direction, for their valuable assistance in carrying out the experiments reported herein.

REFERENCES

1. Th. Paul, *Chemiker Zeitung*, 1899, 535.
2. Walker and Cormack, *J. Chem. Soc.*, 77, 5 (1900).
3. F. Auerbach, *Z. phys. Chem.*, 49, 220 (1904).
4. Lewis and Randall, *Thermodynamics*, McGraw-Hill, 1923, p. 543.
5. R. Pomeroy, *Calif. Sew. Works Jour.*, 6, 54 (1935).
6. R. Pomeroy, *This Journal*, 8, 572 (1936).
7. A. G. Epprecht, *Helv. Chim. Acta*, 21, 205 (1938).

B. The Determination of Sulfides in Sewage and in Sewer Atmospheres

In 1936 the author published a procedure for the colorimetric determination of sulfides in sewage (*This Journal*, **8**, p. 572 (1936)). Since that time more than 20,000 tests have been made by the Los Angeles County Sanitation Districts, and the method has come into general use in southwestern United States where sulfide problems are common.

As a result of experience gained in the intervening five years, minor modifications have been made. It seems appropriate at this time to present in a standard form the procedure which now seems most satisfactory, and to include directions for testing atmospheres and gases.*

Reagents

1. *Stock Amine-Sulfuric Acid Solution.*—Distill para-amino-dimethyl-aniline in an all-glass apparatus from which the air has been displaced by inert gas. Mix 50 ml. of conc. H_2SO_4 with 30 ml. of water and cool. Add to this 20 grams of the purified amine, stirring until solution is complete. Make up to 100 ml. with water.

2. *Amine-Sulfuric Acid Test Solution.*—Dilute 25 ml. of the stock amine-sulfuric acid test solution with 975 ml. of 1:1 sulfuric acid.

3. *Dilute Sulfuric Acid (1:1).*—Mix equal volumes of water and conc. H_2SO_4.

4. *Ferric Chloride Solution.*—Dissolve 100 g. of $FeCl_3 \cdot 6H_2O$ in enough water to make 100 ml. of solution.

5. *Ammonium Phosphate Solution.*—Dissolve 400 g. of di-ammonium phosphate in enough water (805 ml.) to make 1 liter of solution.

6. *Methylene Blue Solution.*—Prepare a solution of 1.00 g. of methylene blue per liter. This should be approximately the correct strength, but, because of variation of different samples of the dye, the solution should be standardized as described hereinafter.

* The sulfide testing sets manufactured by the LaMotte Co. conform to the procedure set forth herein.

7. *Low-Strength Methylene Blue Solution.*—Dilute a portion of the foregoing solution to one-tenth strength.

8. *Aluminum Sulfate Solution.*—Dissolve 24 grams of $Al_2(SO_4)_3 \cdot 18H_2O$ in enough water to make 100 ml. of solution.

9. *Sodium Hydroxide Solution.*—Dissolve 9 g. of NaOH pellets in enough water to make 100 ml.

10. *Zinc Acetate Solution.*—Dissolve 20 g. of zinc acetate in a liter of water.

Procedure for Total Sulfides

Pipette 7.5 ml. portions of the sample into each of two test tubes which are accurately matched as to diameter. To the first tube add 0.5 ml. of the amine-sulfuric acid test solution. To the second tube add 0.5 ml. of dilute sulfuric acid (1:1). To each tube add two drops of ferric chloride solution. Close tubes with the thumbs and mix by inverting slowly once or twice. If sulfides are present, a blue color shows at once in the first tube; color development is complete in one minute. After 1 to 5 minutes add 1.6 ml. of ammonium phosphate solution to each tube and mix.

Prepare standard droppers which deliver 20 drops per ml. (In measuring by drops, hold the droppers steadily in a strictly vertical position. The tips of the droppers must be kept clean so that the drops cling uniformly to the periphery of the outlet.)

Using standard droppers, add the methylene blue solutions dropwise to the second of the two test tubes until the color matches that in the first tube. If these solutions are of proper strength one drop of the stronger will be equivalent to one p.p.m. of sulfide, while one drop of the low-strength solution will be equivalent to 0.1 p.p.m. (A slight error is introduced due to the changing volume of the solution to which the methylene blue is being added. This may be compensated in an average case by making the methylene blue solutions of suitable strength. For greater accuracy water may be added to the first tube to keep the volumes equal.)

Limitations

The foregoing procedure is applicable to samples containing from 0.1 p.p.m. to 20 p.p.m.

Interfering substances were discussed in the former article on this method.

Standardization

Fill a one-gallon bottle with acidified water. Add a washed crystal of sodium sulfide weighing 100–200 mg. Stopper with the bottle completely filled and thoroughly mix.

Pipette 20 ml. of N/40 iodine solution into a 500-ml. volumetric flask. Siphon in sulfide solution from the bottom of the gallon bottle to fill the volumetric flask to the mark. Transfer to a suitable beaker, add 1 ml. of conc. H_2SO_4 and titrate the excess iodine with N/40 thiosulfate.

Multiply the net volume of iodine used by 0.835 to ascertain the concentration of sulfide in p.p.m.

Test the sulfide solution also by the colorimetric method and adjust the methylene blue solutions to give the same result as the iodine titration method.

Dissolved Sulfides

Fill a 100-ml. bottle with sample. Add 0.5 ml. of aluminum sulfate solution and 0.5 ml. of sodium hydroxide solution. Stopper with no air bubbles under the stopper. Rotate back and forth about a transverse axis as vigorously as possible for at least a minute in order thoroughly to flocculate the contents. Allow to settle for 15 minutes, or until the supernatant liquid is reasonably clear. When this liquid is tested by the procedure for total sulfides, the result is the concentration of dissolved sulfides.

Hydrogen Sulfide

Un-ionized hydrogen sulfide is calculated from the pH, the ionization constant of hydrogen sulfide, and the concentration of dissolved sulfides as explained above.

Hydrogen Sulfide in Atmospheres and in Gases

Because of its sensitivity the methylene blue method is useful for the determination of H_2S in atmospheres and gases having not over 0.1 per cent of H_2S. In making such determinations, a measured quantity of the gas or air is drawn through a zinc acetate solution, which is then tested by the foregoing procedure.

The high solubility of H_2S in rubber makes it undesirable to lead the sample to the absorption tube by means of a rubber tube, unless the gas is passed through it for several minutes before drawing a sample, to allow time for establishment of equilibrium. In testing atmospheres the best procedure is to locate the zinc acetate tube in the atmosphere being tested, and to suck a measured amount of air through it.

The zinc acetate absorption tube should be a $\frac{5}{8}$ in. test tube with a 2-hole stopper, having a glass tube to conduct the gas to the bottom, and a short outlet tube. Absorption of H_2S is practically complete when a gas stream is passed through a single tube of this sort.

To aspirate a measured amount of gas it is convenient to use a bottle with a 2-hole stopper, having one glass tube extending to the bottom and another just through the stopper. When this bottle is filled with water and inverted, water will flow from the short tube while an equal volume of air is drawn in through the other tube.

Pipette 7.0 ml. of the zinc acetate solution into the test tube, connect to the aspirator, and draw a suitable volume of sample through the zinc acetate solution. Disconnect, pipette 0.5 ml. of the amine-sulfuric acid test solution through the inlet tube into the zinc acetate solution, and follow this with 0.5 ml. of water as a rinse. Complete the sulfide test according to the preceding directions. Multiply the color reading

in this test by 5730 and divide by the volume of sample in ml. in order to ascertain the concentration of hydrogen sulfide in the gas in parts per million by volume. (This is for 25° C. and one atmosphere pressure. If desired, corrections may be made for other temperatures and pressures by applying the gas laws in the usual manner.)

This method has been extensively used by the Los Angeles County Sanitation Districts for testing sewer atmospheres, with very satisfactory results.

TABLE I.—*Preparation of Permanent Standards for Use in ⅝ In. Test Tubes*
Add the following volumes of solutions to enough water to make 10.0 ml.

P.p.m. of Sulfide	Ml. of Vanadyl Sulfate Solution	Ml. of Cobalt Sulfate Solution
0.1	0.045	0.09
0.2	0.075	0.10
0.3	0.125	0.05
0.4	0.175	0
0.5	0.205	0
0.6	0.235	0
0.8	0.290	0
1.0	0.345	0
1.2	0.400	0
1.5	0.480	0
2.0	0.665	0
2.5	0.915	0
3.0	1.17	0
3.5	1.35	0.05
4.0	1.50	0.18
5.0	1.85	0.44
6.0	2.18	0.70
7.0	2.47	0.97
8.0	2.78	1.24
9.0	3.05	1.51
10.0	3.28	1.78
11.0	3.49	2.05
12.0	3.70	2.33
13.0	3.88	2.63
14.0	4.02	2.93
15.0	4.15	3.24

PERMANENT STANDARDS

Permanent standards made with cobalt sulfate and vanadyl sulfate are useful when much testing is being done, especially for dissolved sulfides and gaseous H_2S. Standards of this kind were calibrated by applying the colorimetric procedure as given herein to sulfide solutions of known strength.

The cobalt sulfate solution may be made by dissolving 7.00 grams of $CoSO_4$, or 12.70 grams of $CoSO_4 \cdot 7H_2O$, and a few drops of H_2SO_4, in enough water to make 100 ml. of solution. Prepare the vanadyl sulfate solution by the procedure given in the previous article on this method, but make up to 8.00 grams of V per 100 ml. of solution. Mix these solutions according to Table I in order to prepare standards suitable for use in ⅝ inch test tubes.

Plant Operation

MECHANICAL FLOCCULATION AND BIOFLOCCULATION OF SEWAGE *

By H. Heukelekian

Associate, Dept. Water and Sewage Research, New Brunswick, N. J.

Flocculation and bioflocculation of sewage are processes of coalescence of finely divided suspended matter. The coalescence of the finely divided suspended matter takes place when sewage is kept under quiescent conditions for prolonged periods. The action is accelerated by mechanical agitation or by air diffusion. It is also promoted by increasing the submerged surfaces.

There appears to be considerable uncertainty in regard to the mechanism of the process whereby finely divided suspended matter of sewage coalesces. The lack of clear understanding of the fundamentals of the process has resulted in confusion of adequate terminology. The terms flocculation and bioflocculation have been used interchangeably depending on whether the biological or physical aspect of the process is emphasized. The boundaries of the process bringing about the coalescence of finely divided suspended matter are drawn on one side by the activated sludge or trickling filter process and on the other by chemical coagulation. The process entails the coalescence of finely divided suspended matter in sewage without the use of activated sludge or other forms of active slime and without the use of chemical coagulants. Undoubtedly, in the activated sludge or trickling filter processes, bioflocculation (the removal of finely divided suspended matter by the biologically active material) is an important phenomenon. To what extent a similar process takes place in the absence of the active biological material is not definitely known. Within the zone covered by flocculation and bioflocculation processes fall a number of ill-defined and borderline phenomena which sometimes are more physical than biochemical and vice versa. If the concept of the varying parts played by physical and biochemical agencies is true then the term flocculation should be used only when physical forces play a primary part in the clarification of sewage, and bioflocculation where biochemical forces play a primary part. It should be remembered, however, that the physical and biochemical agencies are not mutually antagonistic but often proceed simultaneously and may even be difficult to separate one from the other, such as in the initial rapid removal of particulate matter from sewage by biologically active material in activated sludge. The term bioprecipitation (6) is distinguished from bioflocculation by

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

the removal of soluble material rather than suspended matter. In this sense bioprecipitation is the conversion of soluble material into protoplasmic material by the agency of micro-organisms. It does not seem possible that soluble materials can be readily removed by physical forces, since even chemical coagulation leaves this fraction untouched. The term bioflocculation should not be confused with bioaeration which is generally used by the British for the activated sludge process of mechanical type such as Haworth paddles and Simplex aeration. Recently the term biofiltration has come into use to denote the Jenks high rate filter with recirculation of the effluent.

A recapitulation of the connotations of the various terms discussed in the preceding paragraphs is as follows:

Flocculation—Coalescence of finely divided suspended matter in sewage in the absence of biologically active slime, primarily under the influence of physical forces. The term is applied to short period mechanical or air diffusion processes where biological action is at a minimum.

Bioflocculation—Coalescence of finely divided suspended matter in sewage primarily under the action of biological agencies. The conditions which favor this type of reaction are (*a*) long periods either of quiescence or agitation without the addition of biologically active slime, (*b*) short periods in the presence of biologically active slime.

Bioprecipitation—The removal of soluble material from sewage by biological agencies.

Bioaeration—Activated sludge process of mechanical type such at Haworth paddles or Simplex aeration.

Biofiltration—High rate filter with recirculation of the effluent to induce purification.

The phenomenon of flocculation and bioflocculation is one of common occurrence in nature. Slimy growths developing on submerged surfaces such as stones and sticks in a stream are manifestations of this phenomenon. Similarly, some of the growths produced on sewer walls, conduits, tank walls, etc., are excellent sources of organisms which under favorable conditions can bring about clarification of sewage.

In sewage treatment processes we have made use of this natural phenomenon and created environmental conditions and the equipment to foster it. Aeration, mechanical agitation, increasing the submerged surfaces are all efforts in this direction. Thus flocculation and bioflocculation should be regarded as important factors in purification of sewage by such diverse processes as: preaeration and mechanical agitation of sewage, activated sludge, trickling filters, colloiders, and contact aerators. In spite of this, the term should be applied only to intermediate processes of treatment, where coalescence of suspended matter by physical and biological means is the main object of treatment and not to complete purification processes such as activated sludge and trickling filters, which entail other mechanisms of purification besides bioflocculation. However, at times even activated sludge and

trickling filter processes have been employed as pure bioflocculation processes for particular treatment only.

The purpose of this paper is to review the experimental and practical results obtained by flocculation and bioflocculation processes and to analyze critically the evidence produced for physical and biological explanations of the mechanism.

Needless to say, although it is helpful to view these different processes under a unified concept, it will be impossible to develop all phases extensively within the scope of this paper. Certain limitations are necessary.

The subject of stream pollution and complete treatment by activated sludge and trickling filters has been considered beyond the scope of this paper for obvious reasons. Only specialized processes which have been devised for fostering mechanical flocculation and bioflocculation as partial and intermediate processes have been considered.

Most of these processes have two common earmarks. First, they refer to the stabilization of the liquid portion of sewage and not to the coarser solids which can be removed by the force of gravity. Second, they are partially aerobic processes, although sometimes the dissolved oxygen tension may be so low as not to be detected. Generally oxygen diffuses into the liquid at a slower rate than the rate of consumption of oxygen by the microorganisms. Under these conditions there will not be a surplus of oxygen.

The liquid portion of sewage which has been freed from the settleable solids contains a gradation of particles varying in size from colloidal aggregates (finely suspended matter) to true colloids and to material in molecular dispersion. The amount of true colloidal matter in sewage is small (29, 34) and most of the non-settleable non-soluble material in sewage is in a state of colloidal aggregation. This might be taken to indicate that the colloidal material in sewage has a natural tendency to form aggregates or that it is a transitory stage beween larger particles and material in solution.

Bioflocculation can be readily observed by placing in a glass vessel sewage from which the settleable material has been carefully strained. In the course of a day or so discrete particles begin to appear either floating in the liquid, attached to the sides of the vessel or settled to the bottom. This observation was first made by Jones and Travis in 1906.

Theories

Physical.—Several explanations have been offered to account for the mechanism of this phenomenon. They can be grouped into the physical and biological theories. A brief account of these views will be given before passing to the results obtained by the various proposed processes.

Increased internal surface seems to be one of the important factors as first indicated by Jones and Travis (25). They placed glass rods vertically in the liquid and noticed increased deposition taking place on

the surfaces. They were of the opinion that surface attraction was responsible for the deposition and maintained that it could take place in the absence of a gelatinous bacterial layer. Agitation by means of air increased the contact between the liquid and the internal surfaces, transferring the soluble and colloidal organic material into a particulate condition. The effect was due to mechanical action of air and could be brought about by other mechanical means.

Biltz and Kröhnke (5) on the other hand were of the opinion that the colloidal matter in sewage was adsorbed by the aerobic growth consisting of the colonized forms of plants and animals. They suggested the formation of an adsorption compound of the colloidal matter and the gelatinous coating. This was followed by oxidation or conversion of the adsorbed matter directly by the oxygen of the air essentially by chemical means. Thus the biological growth was admitted to be important only in furnishing adsorptive surfaces.

Melling (28) stated that clarification of sewage by aeration was more physical than biochemical. The evidence produced is based on the small removal of oxygen absorbed values obtained by aeration after sterilization of sewage by $HgCl_2$. It is not stated whether actual sterilization was obtained or maintained during the aeration period. Furthermore the small removals might be attributed to the coagulation produced by $HgCl_2$.

Williams (41) studied the coagulation of suspended matter in sewage by bubbling different gases through the liquid. He observed that the coagulation obtained by air, oxygen, nitrogen and hydrogen over a 6 hour period was not materially different. Bubbling these gases over a period of 24 hours, however, gave the following order of efficiency: oxygen, air, nitrogen, hydrogen. He concluded from these observations that chemical or biological effects or both were present though they may be small in comparison with the physical effects. Bubbling the different gases through sewage at different temperatures gave little if any coagulation a 0° and 10° C. At 25° and 37° C. the clarification of the suspended matter by the different gases was greatly increased. These results might indicate a biological factor. At 80° C. slightly better coagulation was obtained than at 25 or 37° C., possibly due to heat coagulation. The removal of suspended material by gas bubbles would appear to be due to the combined action of two different processes: (1) Biological changes operative only at temperatures of 25° and 37°, (2) coagulation by physical means alone at 80° C. Since, however, normal sewage temperatures never reach 80° C. the last factor may be disregarded.

In a subsequent publication Williams (42) attempted to exclude bacterial action by sterilizating the sewage. He used potassium cyanide and mercuric iodide as the most suitable substance for this purpose, to give effective sterilization without changing the nature and stability of the system. Passing air and oxygen through sewages treated in this way, greatly reduced if not entirely stopped coagulation of the dispersed material. This might be interpreted as being due to the in-

hibition of bacterial and enzymic activity but Williams favored the alternative explanation that surface poisoning was produced, preventing coagulation. In support of this view he cited that extensive bacterial growth could be obtained with the material treated with potassium cyanide. It might be stated, however, that no quantitative figures were given showing the percentage reduction of bacteria obtained by the different disinfectants. It is further possible that the organisms specifically responsible for the coagulation were more effectively inhibited by the disinfectants than the organisms capable of growing on agar. Williams further tried to obtain coagulation by means of different gases after sterilizing the sewage by ultraviolet rays and showed that coagulation was somewhat reduced as a result of exposure to the rays. He concluded from these experiments that coagulation must be due to some action of a physical nature. The same objections could be raised, however, for these experiments as in the case of the use of disinfectants in as far as sterility was not obtained.

Formation of new surfaces by the deposition of carbonates from carbon dioxide did not increase the coagulation of dispersed matter by the action of different gases bubbled through sewage (43).

Rudolfs and Gehm (35) stirred sewage in the presence of air, oxygen ozone, nitrogen, carbon dioxide and hydrogen peroxide and also subjected it to the bubbles of the same gases without the aid of stirring. Increased removals of B.O.D., turbidity and suspended solids over plain settling were observed. During short periods of one-half hour all gases showed approximately the same removals with no reduction in soluble B.O.D. It was suggested that B.O.D. removals were caused by the removal of finely divided material by physical agglomeration. Continued treatment led to B.O.D. reductions in the soluble fraction when oxygen bearing gases were used. The removal of suspended solids on continued treatment was the same with all the gases. Oxidation was greater with diffusion of air as compared with stirring but turbidity removal was somewhat poorer. Under laboratory conditions over 40 per cent suspended solids, 25 per cent turbidity and 30 per cent B.O.D. could be removed in excess of plain sedimentation.

Biological.—Fowler and Mumford (14) isolated an organism "M 7" from pit water, added it to settled sewage with a small dose of ferric salt and blew air through it for about 6 hours. The coagulated matter was removed by secondary settling, leaving a clear liquid.

Baker (3) by sterilizing sewage by means of formaldehyde concluded that biological action was necessary for purification.

Whitehead and O'Shaughnessy (40) concluded that the gelatinous matrix produced by bacterial agents in water containing suitable nutrient substances in the presence of oxygen, furnishes the basis for purification. They stated that the process was one of integration under the influence of the living agent. They observed that there was hardy any difference microscopically between the gelatinous matrix produced when sewage was allowed to stand, the slime collected from a surface in a mildly polluted stream and activated sludge. As indicated

previously this tends to bring all these different phenomena as a manifestation of the same process varying naturally as to degree. It is to be expected that the organisms involved, though closely allied, belong to different species not only in stream, sewage and activated sludge, but also within the same process at different times. Whitehead and O'Shaughnessy indicate that inert materials such as silt and clay may form the nuclei for the organisms around which they build their colonial gelatinous growth. They went even further and specified the size of the foreign particle which living agents could utilize for this purpose (.02 mm.). Particles larger than this were rejected.

Butterfield (7) also stressed the importance of an inert foreign substance (cotton fibers) to act as a binder and framework for the floc formed by pure culture of the organism to be isolated.

Dienert (11) made observations on the self-flocculation of sewage in contact with glass vessels and advanced the explanation that bacteria capable of purifying sewage fix themselves on the glass when they don't find anything else on which to deposit. By inoculating sterile sewage with a trace of the deposit formed on glass, sewage became rapidly clarified. He explained that these deposits contained aerobic coagulating bacteria of which there are many species. These bacteria are small agglomerated rods and fail to grow on agar. The attraction of the organism is ascribed to the difference in the charge of organism and the glass the former being electro-positive and the latter electro-negative.

There is ample evidence that surfaces are important for the development of bacteria. Zobell and Anderson (45) found that bacterial development in stored sea water was higher with greater amount of surface exposed. This was attributed to the contact of the water with larger solid surface area. Solid surfaces provide a resting place for periphytic bacteria and concentrate the nutrients upon the solid surface. Measurable amounts of soluble organic matter accumulated over a period of hours on the surface of clean glass slides when suspended in sterile lake water (36). This shows that the accumulation of organic matter may proceed independently of bacterial growth. Heukelekian and Heller (22) showed that the growth of B. coli in very dilute medium (5–25 p.p.m. dextrose peptone) was dependent on the presence of additional surface in the form of glass beads. It was further shown that the action of aeration and agitation was similar to the action of solid surfaces such as sand in promoting the growth of bacteria in surface waters. Shive and Buswell (6) have shown that when *B. subtilis* was grown in a quiescent clear broth very little growth was obtained and consequently very small amount of the nitrogen in the substrate was precipitated in the form of bacterial cells. By aerating the substrate containing the organism, very heavy growth was obtained which settled readily as white flocculent sludge leaving a clear supernatant liquor. A considerable part of the soluble nitrogen originally present in the substrate was precipitated in the sludge formed as a result of the growth of the bacteria and the conversion of the soluble

food material in the substrate to protoplasmic growth. The experiment conclusively proved the generally accepted view that available soluble food material can be transformed directly by the growth of bacteria to insoluble colloidal aggregates of protoplasm. It is doubtful however whether the test organism used is of any real significance in the clarification and the flocculation of sewage.

The difficulty arises in explaining flocculation of the insoluble colloidal and pseudo colloidal material directly by the agency of bacteria. In this case it will be necessary to previously hydrolyze and convert the insoluble particles to diffusible forms available for bacteria. Whether this action takes place in the liquid phase or whether the particles are first concentrated on the surfaces prior to hydrolysis and assimilation is the problem. That the presence of an already formed bacterial slime accelerates the rate of flocculation and clarification is undisputed. But what is the cause of the acceleration? Is it mass inoculation with specific organisms or the presence of the organisms creating an adsorptive surface wherein the processes of hydrolysis and oxidation may be carried out at a more accelerated rate?

It is gradually becoming recognized that in the clarification and flocculation of sewage we are dealing with special types of bacteria which refuse to grow on conventional culture media. It has also been demonstrated that the true water and sewage organisms have the peculiar characteristic of sticking to submerged surfaces and there forming colonial growths known as zooglea. The number of individuals in a given colonial growth of zooglea may run into tens of thousands and constitute the major portion of solid matter. It is to this highly developed biological growth that we have to look for an answer. Whether the cells act directly as such, as they may well do with certain soluble materials in sewage, or whether they may become operative through their enzymes secreted in the liquid phase, or whether by some agency the insoluble materials are first adsorbed on the surfaces of the growth we cannot answer definitely yet. It should be mentioned that organisms in the colonial growth are enveloped by cellular secretion product—the zoogleal slime, which may play a part as an adsorptive surface. When the final chapter in this story is written it will possibly be shown that all these factors play a part. The soluble material may be directly removed by the bacteria as a result of direct assimilation. Some of the insoluble colloidal particles and their aggregates may be hydrolyzed in the liquid phase by the enzymes that are secreted while with other particles a preliminary stage of adsorption prior to hydrolysis and oxidation may be necessary.

Some investigators have considered protozoa as an important factor in the clarification and flocculation of sewage. Cramer (10) erroneously concluded, from the failure of organisms isolated from agar plates inoculated with sewage to cause clarification when returned to sewage, that protozoa were necessary for clarification. It has been pointed out previously that such a method will fail to yield bacteria responsible for clarification. There is also little justification for main-

taining that the failure of sludge heated to 60° to clarify sewage was only due to the absence of protozoa as many of the organisms responsible for clarification might have been similarly affected. Viehl (38) concluded that the oxidation of dissolved organic matter is carried on by bacteria alone but the flocculation and adsorption of colloids is dependent on the presence of protozoa in general and ciliates in particular. Bacteria cannot take up the insoluble particles so readily. They must be made soluble by enzymes. The flagellates stand in between the bacteria and ciliates in this respect.

Practical Developments, Devices and Results

Contact Aerators.—Jones and Travis (25) constructed at Hampton, England in 1906 their hydrolyzing chambers which translated into practice their observations and theories. These tanks offered large submerged surfaces (broken flint 3 in.) to the settled sewage and removed material in solution and suspension. Provision was made to withdraw the deposited matter. Sewage went through four chambers in succession in three hours. A reduction of 63.8 per cent in albuminoid matter was obtained. Later Travis used laths placed vertically 6 to 9 in. apart. The material collected on the laths until it dropped off.

Black and Phelps (4) placed in their aeration tanks laths vertically and horizontally one inch apart and at an angle of 45°. These laths offered a large surface for the development of bacterial growths as well as impeding the passage of air upwards.

This method was later modified and used by Levine (26) in treatment of milk wastes over lath filters.

In 1912 at the Lawrence Experiment Station (9) layers of slate were placed in a tank first horizontally and then vertically one inch apart and the sewage was constantly aerated by means of a pipe. Aeration time was reduced from 24 hours to 5 to 6 hours in successive stages. Air input was varied from .025 to .2 cu. ft. per gallon of sewage. The area exposed by the slates was 1 to 1.7 sq. ft. per gallon of sewage. The efficiency of purification was affected only slightly by wide differences in the aeration time and the amount of air employed. The value of gelatinous growths was recognized. With the slates in a vertical position the growths sloughed off in large flakes and fell to the bottom of the tank. The sludge was inoffensive and resembled sludge from trickling filters. The shortcomings of the device were (1) insufficient surface area, (2) inadequate facilities for the removal of flocculated material giving rise to septicity, liquefaction and redispersion, (3) failure to maintain aerobic conditions.

In spite of these difficulties, sewage aerated for a period of 24 hours and settled could be applied on intermittent sand filters at a rate of 250,000 gallons per acre per day as compared with 50,000 gallons per acre per day application for non-aerated sewage. The rate of application on trickling filters could be increased from 1,000,000 to 6,500,000 gallons per acre per day as a result of aeration in slate tanks for a period of 10 hours.

The slates and sides of the tank became covered with a compact brown growth which was stated to collect, mechanically, suspended matters in sewage. This was a new feature discovered as to the effect of aeration on sewage, since prior investigations had shown that aeration did not hasten the oxidation of sewage. It was also a new departure from the earlier (1891–1898) experiments at Lawrence Experiment Station where the effect of artificial aeration of sewage filters was studied.

In 1913 the experiments on the aeration of sewage with and without inoculation of green growths were confirmed and expanded. Studies were made on the reduction of different forms of nitrogen and production of nitrates. The inoculated and aerated sewage contained 15 p.p.m. nitrates. Inoculation and aeration gave better nitrification than aeration alone. The heavier the green growths on the sides of the bottles the clearer were the effluents. The aerated bottles were cleaned when green growths appeared on the glass. As the aeration time was reduced from 24 to 18 hours the oxidation of ammonia became inappreciable and with further reduction of the aeration time to 6 hours the removal of organic nitrogen and carbonaceous matter was affected. The rate of application of aerated sewage on sand filters was increased to 400,000 gal. per acre.

The nidus tank of Buswell (6) was designed to meet these shortcomings. The submerged surfaces initially used were racks. Later brushwood, cotton and hemp strings and laths were tried. Veneer frame was found the most satisfactory material. The racks or frames were lifted up and down in the liquor to break off the accumulated material. Aeration was provided from perforated pipes in the bottom. The most suitable ratio of surface to volume was stated to be 20 to 1. Thirty to forty per cent of the non-settleable colloidal matter of sewage was removed.

The original Emscher filter developed by Bach (2) consisted of a tank filled with coke and pipes at the bottom for aeration. Imhoff (24) placed the submerged contact aerators in special sedimentation tanks or in flowing through compartments of Imhoff tanks. Air was blown intermittently from the bottom through perforated pipes, swinging from side to side like a pendulum (2 to 6 oscillations per minute). Air consumption was .2 cu. ft. per gal. of sewage. The contact material was placed in wooden boxes open at the bottom and the top. Imhoff emphasized the continuous circulation of the sewage in the filters. With a detention period of .5 to 1.0 hour, from 30 to 40 per cent reduction in the B.O.D. of the settled sewage was obtained. Imhoff claims that the process is best adapted for partial treatment or for pretreatment to remove the load from oxidizing units. It has the advantage of low cost of construction and not being readily upset by toxic discharges.

Mahr and Sierp (27) have reported the results of tests with the Imhoff contact aerators in different plants in Germany. Treating presettled sewage with a detention time of 8 to 10 minutes in the contact aera-

tors and an air consumption of .13 to .4 cu. ft. per gallon B.O.D. reduction of 28 to 69 per cent was obtained. The materials used were veneer mats or horizontal wood laths placed on a slant to prevent sludge deposition. They state the organisms in contact aerators were different than those in trickling filters. Sewage fungi play an important role in contact aerators.

A contact aerator was constructed in one of the Imhoff tanks at Brighton treatment plant, Rochester, N. Y., in order to relieve the load from the trickling filters (1). They were regular Imhoff submerged contact aerators placed in the center portion of the sedimentation compartment of the Imhoff tank. The medium used was coke. During early months of operation the contact aerator effected a marked reduction in suspended solids in excess of that by the Imhoff tank alone but during later months this advantage entirely disappeared. The unsatisfactory results were attributed to failure of flushing the accumulated sludge from the coke. To correct this the entire volume of air was passed through once a day. The aerator removed an additional 30 per cent of oxygen consuming material over the Imhoff tank effluent.

Thackwell (37) at Jacksonville, Texas, used brushwood as the contact medium. Settled sewage was retained for 1 hour in the contact aerators with an air input of .25 cu. ft. per gal. Thackwell concluded that the effect of contact aeration on settled sewage was largely a physical one in the nature of clotting action.

Hayes and Bassel (19) have modified and extended the contact aerator to embrace complete purification of sewage. The first tank which is called a coagulation tank contains thin building tile as submerged surfaces. Settled sewage is brought in contact with these surfaces which are coated with slime producing organisms. The deposited sludge is settled and thereafter the liquid is passed upward through a bed of ¾ to 3 in. stone. Here oxidation takes place. Both the coagulation and oxidation tanks are aerated. Air input is 1.25 to 1.8 cu. ft. per gallon of sewage at 2.6 lbs. pressure through pipe grids. The detention time in the coagulating tank is 45 minutes and in the oxidation tank 1 hr. and 40 minutes; 15 million gallons could be treated on an acre. An overall reduction of B.O.D. and suspended solids of 93 to 94 per cent is obtained with 16 p.p.m. nitrate N. in the final effluent. Estimated cost is given at $41,500 per m.g. Power cost is estimated to be 50 per cent less than that for activated sludge.

Mechanical Flocculation.—Another method of utilizing the bioflocculation phenomenon by means of submerged surfaces is described by Doman (12). A series of rotating contact plates fastened to a horizontal shaft are alternately submerged into the sewage and exposed to air. In the first tests the sewage used was septic and results obtained were poor. Therefore the sewage was preaerated by running it over three trays. Contact time was increased from 1.7 to 2.4 hours. The revolution of the plates was reduced from 1 per minute to ½ per minute. Much thinner coating of slime accumulated on the plates. Purification was increased, yielding 75 to 90 per cent removal of turbidity.

Twenty-seven per cent removal of oxygen consumed and 80 per cent removal of suspended solids was obtained.

Mechanical flocculation of a mixture of packing house waste and sewage was practiced at Cedar Rapids, Ia. (17). Improved suspended solids and B.O.D. removals were obtained over plain sedimentation.

Gehm (15) studied the effect of mechanical agitation at New Brunswick as an aid in flocculation and improved removals. Agitation was brought about by paddle type flocculators. A peripheral velocity of 1.8 ft. per second was found to prevent settling in the flocculating chamber. The removals of suspended solids increased with longer periods of flocculation up to four and a half hours. The maximum additional removal of suspended solids over plain settling was 27 per cent. The removals of suspended solids plotted against time of flocculation formed a straight line up to 4½ hours, the maximum period reported. Even with shorter periods of flocculation better effluents were obtained than by plain settling alone.

Under laboratory conditions using a model mechanical flocculator and a rotary type mixing machine the same author (16) found only little improvement in the removal of suspended solids and turbidity by flocculation period beyond a half hour. An amount equal to that removed within the first half hour could be obtained only after 4½ hours of additional flocculating time. By using 30-minute flocculation and one hour settling and comparing against two-hour plain sedimentation the additional removals obtained increased with higher initial suspended solids concentration. Fischer and Hillman (13) conducted extensive laboratory and plant scale experiments with mechanical flocculation. The general conclusion drawn was that improved clarification may be obtained by the use of flocculation without chemicals. Preflocculation may be used to advantage in sewage clarification either as a means of increasing suspended solids removal or increasing the clarifier capacity or both. The recommended detention time in the flocculator is 30 to 40 minutes with clarifier detention time 1.5 to 2.0 hours. In the design of the settling tank overflow rates are more important than detention time. Flocculator velocity should not exceed 1.5 ft. per second and there should not be undue inlet and outlet disturbances.

Flocculation by Means of Air.—Preaeration of sewage has been practiced in a number of plants with different objectives. One of the main benefits derived is the removal of grease. Roe (33) reports that as high as 7 cu. ft. of grease per million gallons of sewage may be removed by preaeration. At Dodge City, Kansas, with a preaeration period of 13 minutes the removal of grease varied from 44 to 63 per cent. Considerable removals of B.O.D. (13 to 74 per cent) and suspended solids (55 to 83 per cent) were also obtained at this plant.

Heukelekian (21) has shown that plain aeration of sewage for six hours does not decrease the suspended solids or the B.O.D. appreciably unless the sewage is subsequently settled. In other words the reductions due to actual oxidation were very small. On settling the sewage (after six hours of aeration) appreciable reduction of B.O.D. and of

suspended solids took place which were above the values obtained by sedimentation without aeration (20). The increase in removals due to aeration varied with different sewages. An additional removal of 16 to 22 per cent of suspended matter was obtained over plain sedimentation by six hours preaeration. The overall reduction of suspended solids by preaeration and sedimentation was 50 to 60 per cent. The increase in B.O.D. removal due to aeration varied from 4 to 45 per cent with different sewages and an overall B.O.D. reduction of 40 to 50 per cent was obtained.

Aeration of settled sewage without activated sludge by means of wooden paddles was described by Ridenour (32) in 1931 at an institutional plant as an auxiliary to a trickling filter. The actual detention time in the aeration tank was 9.0 hours. The aerated sewage was not settled before application on the trickling filter. The suspended solids of the sewage increased and turbidity decreased at the effluent end of the aerator due to the flocculation of finely divided suspended matter. The B.O.D. was reduced by 41 per cent. Ammonia nitrogen was reduced by 33 to 40 per cent although no nitrites or nitrates were found. There was 0.5 to 1.0 p.p.m. dissolved oxygen in the aerator. Samples taken at different points along the aerator showed that practically the entire B.O.D. reduction occurred with a detention time of 3¾ hours.

Hatfield (18) reported the results of preaeration of sewage at Decatur. With 2.48 hrs. of aeration and an air supply of .41 cu. ft. per gallon of sewage, 33 per cent reduction of B.O.D. was obtained. With the introduction of a small amount of activated sludge (9 per cent by volume which increased the suspended solids in the mixture from 105 to 190 p.p.m.) the B.O.D. reduction was not increased. Further experiments showed that with air application in the plain aeration of sewage of .17, .29 and .41 cu. ft. per gallon of sewage the reduction of B.O.D. was 17.5, 28.8, and 37.2 per cent respectively.

Calvert and Bloodgood (8) found that plain aeration of all the sewage under the conditions existing at the Indianapolis plant gave overall higher B.O.D. removals than complete treatment of a part of the sewage by the activated sludge process. The percentage removal with plain aeration was lower than with activated sludge process. The sludge produced by plain aeration differed considerably from activated sludge. It had a lower N. and higher fat content than activated sludge.

Experiments were made to determine the effect of increasing the internal surface with plain aeration of sewage. The material used was hollow building tiles dipped in cement mortar to roughen the surfaces. These were stacked in chimney fashion. The submerged area of the tank was increased from 26,500 sq. ft. to 60,000 sq. ft. Comparisons over a three months period were made with a similar tank without increased submerged surfaces. There were only slight differences in the effluents from the two tanks which did not warrant the installation of additional surfaces.

Hyde (23) reports the results from the San Francisco experimental plant on the removal of grease from sewage by preaeration. The ex-

periments indicated .05 cu. ft. of air per gallon of sewage to be ample with the 15-minute aeration period. Earlier work with paddles indicated an improvement of 15 to 30 per cent in the oxygen demand of sewage as compared with unstirred sewage. "Self flocculation" of the sewage without chemicals has been incorporated in the design of the projected plant.

Zigerli (44) added finely divided asbestos fibers to clarified sewage passing to the aeration chamber. After 1 hour aeration and sedimentation the effluent was passed through slag at a high rate. Part of the settled sludge was returned to the aeration chamber and 95 per cent reduction of suspended solids and 80 per cent reduction of B.O.D. was obtained with 1 hour aeration period.

O'Shaughnessy (30) has practiced bioflocculation of sewage at Birmingham with the primary purpose of deodorizing the septic sewage applied on percolating filters. Bioflocculation is accomplished by aeration of the settled sewage with activated sludge for 1 hour. After separation of the liquor the sludge is regenerated by re-aeration. He was able to apply the sewage thus treated at a higher rate on the trickling filter.

Pipe and Farmer (31) used partial treatment of sewage with activated sludge (2 hrs.) to relieve the load from trickling filters and increase the rate of filtration (2 fold). Partial treatment of this nature gave good flocculation of solids and colloidal matter but little if any removal of soluble matter. The flocculation was accomplished by the growth of filamentous bacteria on every particle of organic solids which coalesce to form a floc. The floc formed by such partial treatment was different in appearance and quality than that formed by full treatment. Sludge volume carried should not be in excess of 4–5 per cent. The process is more delicate and can be more readily upset than full treatment by activated sludge.

It might be of interest to mention that Whitehead and O'Shaughnessy (39) have considered self-purification as one of the functions of the sedimentation tanks. They recommend long detention periods (10 to 12 hours) during which time self-purification of sewage takes place in addition to the settling of the solids. To show that self-purification was due mainly to biological action they chlorinated the sewage entering one sedimentation tank while another similar tank was not chlorinated. The effluent from the non-chlorinated tank had a lower oxygen absorbed value while the effluent fron the chlorinated tank was similar to the influent of the tank.

Discussion

The evidence presented in the foregoing pages both from theoretical and practical aspects seems to warrant the following generalizations:

1. Finely dispersed matter in sewage is amenable to flocculation.
2. The flocculation is brought about both by physical and biological agencies working either independently or simultaneously. The above generalization is based on the following observations:

(*a*) Removal of dispersed matter from sewage can be accomplished under sterile conditions.

(*b*) The removals are appreciable with short periods of flocculation which in the absence of a mass of active biological slime is an inadequate period for biological action to take place.

3. Flocculation takes place under quiescent conditions. Increasing the internal surface accelerates the flocculation. The internal surface may be increased by (*a*) adding clean solid materials, (*b*) agitation, (*c*) aeration. When the internal surfaces become coated with an active biological slime the rate of removal is further accelerated. Internal surfaces furnish a contact between the bacteria and their food. There is evidence that a clean surface may concentrate even soluble material. When the surfaces become coated with biological growth the rate of removal of both dispersed and soluble material is increased.

4. The removal accomplished with short periods of flocculation (physical) does not seem to require aerobic conditions, while removals over longer periods (biological) are aided by the presence of air.

5. Mechanical flocculation and bioflocculation proceed simultaneously. The former plays a more important role during short periods. As the period is increased bioflocculation plays an increasingly important role.

A number of developments are available which exploit the flocculation and bioflocculation processes for the purification of sewage. They are primarily designed to provide only intermediate or partial treatment of sewage although they may readily be followed by the more complete processes of oxidation. They have been used (1) to improve the performance of settling tanks, (2) for relieving the load on secondary treatment processes and (3) for removal of grease or odor. The results accomplished are variable but substantial and may be favorably compared with chemical coagulation processes. The advantage over the latter should be economy of operation. Mechanical flocculation and bioflocculation devices give performance values materially lower than trickling filters but they are usually free from odor and fly problems.

Several difficulties in operation have arisen with the contact aerators due to insufficient appreciation of the basic principles. It should be borne in mind that submerged contact aerators are only biological flocculators and should only be used as such. There should be no attempt to hold the sludge on the submerged surfaces any longer than absolutely necessary, because then the process becomes reversed and deflocculation and resolution takes place. The importance of adequate and prompt removal of sludge cannot be over emphasized. Furthermore organisms responsible for bioflocculation operate best under aerobic conditions and a provision should be made to supply this need. Increased internal surface is another necessary condition, although the process takes place even when sewage is allowed to stand in a quiescent condition without increased surface. The increase in the internal sur-

face may be accomplished in one of many ways—submergence of inert media such as laths, brushwood, veneer frame, corn cobs, strings, corks, coke, slag, etc. In the selection of the material consideration should be given to its endurance under the conditions of use although a material such as brushwood or corn cobs which can be cheaply obtained may be discarded occasionally when deteriorated. The materials used should increase the internal surfaces materially (20:1). The failure of the Indianapolis experiment to yield favorable results with increased internal surfaces might be attributed to this factor. Other materials such as clay, silt or asbestos fibers will accomplish the same end by furnishing nuclei for the organism for attachment and development. These materials might be used to advantage in conjunction with plain aeration of sewage.

Stirring and aeration should be considered as another means of increasing the internal surface. The modern trend in the flocculation of finely divided suspended matter is away from submerged contact aerators towards mechanical and diffused air flocculation processes. The latter methods of flocculation offer several advantages. In the first place flocculation and sedimentation are brought about in separate chambers, thus eliminating the drawback encountered in most contact aerators with septic conditions created by accumulation of sludge. In the second place the surfaces treated by mechanical agitation and air diffusion processes are greater and hence flocculation is more pronounced. Finally, it might be suggested that aeration brought about by these processes may play a role in bringing about more efficient flocculation. The main disadvantage of mechanical and air diffusion methods of flocculation is the lightness of the floc and the ease with which the floc may be dispersed by high velocities in the flocculating chamber. The velocity should be high enough to prevent sedimentation in the flocculator and yet not too high to break up the floc. Fischer and Hillman (13) state that the velocity of the flocculator should not exceed 1.5 ft. per second. To remove the stray floc that may pass out into the effluent a straining device would be a positive safeguard.

References

1. Anon, "Contact Aerator at Rochester, New York." *Public Works*, **59**, 369 (1928).
2. Bach, H., "The Emscher Filter, a New Form of Biological Filter for Sewage Purification." *Wasser and Gas.*, **16**, 9 (1926).
3. Baker, G. C., "Some Factors in the Purification of Sewage by the Activated Sludge Process." Univ. Ill., *Bull.*, **16**, 182 (1918).
4. Black, W. M., and Phelps, E. E., *Report on Location of Sewer Outlets and the Discharge of Sewage into New York Harbor*, **64**, 78 (1911).
5. Biltz, W., and Kröhnke, O., "Uber organische Colloide aus stadtischen abwässern und deren Zustandsaffinitat." *Ber. Deutchen Chem. Gesel*, **37**, 1745 (1904).
6. Buswell, A. M., Shive, R. A., and Neave, S. L., "Bioprecipitation Studies." Ill. Water Survey, *Bull.*, **25** (1928). Also *This Jour.*, **1**, 187 (1929).
7. Butterfield, C. T., "Studies on Sewage Purification. II. A Zooglea-forming Bacterium Isolated from Activated Sludge." *Pub. Health Repts.*, **50**, 671 (1935).
8. Calvert, C. K., and Bloodgood, D. E., "Operation Experiments at the Indianapolis Activated Sludge Plant." *This Jour.*, **6**, 1068 (1934).

9. Clark, H. W., "Past and Present Developments in Sewage Disposal and Purification." *This Jour.*, **2**, 561 (1930). Also Mass. State Boards of Health Rpt., p. 288–294 (1913). Mass. State Board of Health Rpt., p. 301–309 (1914).
10. Cramer, R., "The Role of Protozoa in Activated Sludge." *Ind. Eng. Chem.*, **23**, 309 (1931).
11. Dienert, F., "Clarification of Sewage by Bacteria." *Comp. Rend. Acad. Sci.*, **200**, 1253 (1935).
12. Doman, J., "Results of Operation of Experimental Contact Filter with Partially Submerged Rotating Plates." *This Jour.*, **1**, 555 (1929).
13. Fischer, A. J., and Hillman, A., "Improved Sewage Clarification by Preflocculation without Chemicals." *This Jour.*, **12**, 280 (1940).
14. Fowler, G. J., and Mumford, E. M., "Preliminary Note on the Bacterial Clarification of Sewage." *Jour. Royal San. Inst.*, **34**, 497 (1913).
15. Gehm, H. W., "Bioflocculation at the New Brunswick, N. J., Sewage Treatment Plant." *Water Wks. and Sew.*, **85**, 1072 (1938).
16. Gehm, H. W., "Mechanical Bioflocculation." *Proc. New Jersey Sew. Wks. Assoc.*, **108** (1938).
17. Green, H. R., and McIntyre, J. C., "Flocculation Studies." *Water Wks. and Sew.*, **84**, 383 (1937).
18. Hatfield, W. D., "Operation of the Pre-aeration Plant at Decatur, Ill." *This Jour.*, **3**, 621 (1931).
19. Hayes, C. C., and Bassel, B. A., "Recent Developments in Sewage Disposal." *Proc.* 14th Texas Water Works Short School, 127 (1932). "A New Method of Sewage Disposal by Coagulation, Sedimentation and Oxidation. *Proc.* 15th Texas Water Works Short School, 28 (1933). "Application of Oxidation Principles to Small Town Sewage Disposal Plants." *Proc.* 16th Texas Water Works Short School, 93 (1934).
20. Heukelekian, H., "Effect of Aearation on the Rate of Oxidation of Activated Sludge Mixtures." *This Jour.*, **6**, 897 (1934).
21. Heukelekian, H., "Purification of Sewage by Aeration." *This Jour.*, **7**, 393 (1935).
22. Heukelekian, H., and Heller, A., "Relation between Food Concentration and Surface for Bacterial Growth." *Jour. Bact.*, **40**, 547 (1940).
23. Hyde, C. G., "Sewerage and Sewage Treatment in Review." *Water Wks. and Sew.*, **84**, 71 (1937).
24. Imhoff, K., "Submerged Contact Aerators for Sewage Treatment." *Eng. News Rec.*, **97**, 948 (1926).
25. Jones, A. S., and Travis, W. O., "On the Elimination of Suspended Solids and Colloidal Matter from Sewage." *Proc. Inst. Civil Eng.*, **164**, 68 (1926).
26. Levine, M., Burke, G. W., and Linton, C. S., "Purification of Skimmilk Solutions on a Lath Filter." Ia. State College Eng. Exp. Sta., *Bull.*, **81** (1924).
27. Mahr, G., and Sierp, F., "Erfahrungen beim Bau und Betriebe von Tauchkörpern." *Techn. Gemeindeblatt*, **10** (Sept., 1928).
28. Melling, S. E., "The Purification of Salford Sewage Along the Lines of the Manchester Experiment." *Jour. Soc. Chem. Ind.*, **33**, 1124 (1914).
29. Mills, E. V., "Studies on the Nature and Amount of the Colloids Present in Sewage. Part II. The Physical and Chemical Analyses of Sewage." *Jour. Soc. Chem. Ind.*, **51**, 349T (1932).
30. O'Shaughnessy, F. R., "Some Consideration in the Oxidation of Sewage." *Proc.*, Assoc. Managers Sew. Disp. Wks., p. 74 (1931).
31. Pipe, F. E., and Farmer, J. E., "Partial Treatment of Sewage by the Activated Sludge Process. Comparative Working of the 'Air Diffusion' 'Channel' and 'Simple Methods at Croyden.' " *Surveyor*, **91**, 437 (March 19, 1937).
32. Ridenour, G. M., "Aeration as an Auxiliary to Trickling Filter Treatment." *Pub. Wks.*, **62**, 19 (Feb. 1931).
33. Roe, F., "Pre-aeration of Sewage by Air Diffusion." *Pub. Wks.*, **64**, 15 (1933).
34. Rudolfs, W., and Gehm, H. W., "Colloids in Sewage and Sewage Treatment. I. Occurrence and Role. A Critical Review." *This Jour.*, **11**, 727 (1939).

35. Rudolfs, W., and Gehm, H., "Chemical Coagulation of Sewage. VIII. Removal of Suspended Solids and B.O.D. by Stirring and Diffusion of Gases." *This Jour.*, 9, 579 (1937).

36. Stark, W. H., Stadler, J., and McCoy, E., "Some Factors Affecting the Bacterial Population of Fresh-water Lakes." *Jour. Bact.*, **36**, 653 (1938).

37. Thackwell, H. L., "Submerged Brushwood Contact Aerators at Jacksonville, Texas, Sewage Works." *Eng. News-Rec.*, **102**, 35 (1929).

38. Viehl, K., "Untersuchungen über das Wesen der Selbstreinigung des Abwassers." *Zeit. Hyg. und Infektionskrankheiten*, **119**, 383 (1937).

39. Whitehead, H. C., and O'Shaughnessy, F. R., "Factors in the Design Disposal Works." *Inst. Sew. Purf.*, Part II, **350** (1935).

40. Whitehead, H. C., and O'Shaughnessy, F. R., "Improving the Efficiency of Activated Sludge." *Surveyor*, **89**, 407 (1936).

41. Williams, E., "Studies on the Nature and Amount of the Colloids Present in Sewage. Part VII. The Effect of Bubbles of Gas and Agitation on Sewage Liquors." *Jour. Soc. Chem. Ind.*, **54**, 355T (1935).

42. Williams, E., and Murray, K. A., "Studies on the Nature and Amount of the Colloids Present in Sewage. Part VIII. The Effect of Bubbles of Gas on Sterilized Sewage Samples." *Jour. Soc. Chem. Ind.*, **55**, 281T (1936).

43. Williams, E., "Studies on the Nature and Amount of the Colloids Present in Sewage. Part X. Further Experiments on the Effect of Bubbles of Gas on Sewage." *Jour. Soc. Chem. Ind.*, **57**, 449 (1938).

44. Zigerli, P., "Das 'Z' Verfahren als neuer Beitrag zur Abwasserreinigung." *Ges. Ing.*, **60**, 499 (1937).

45. Zobell, C. E., and Anderson, D. Q., "Observations on the Multiplication of Bacteria in Different Volumes of Stored Sea Water and the Influence of Oxygen Tension and Solid Surfaces." *Biol. Bull.*, **71**, 324 (1936).

PUBLIC RELATIONS IN THE CONSTRUCTION AND ADMINISTRATION OF SEWAGE WORKS*

By C. R. Velzy

Works Superintendent, Buffalo Sewer Authority, Buffalo, New York

At a meeting of this Association held in October, 1939, at Olean, the program included a symposium on the subject, "An Operator's Day at a Sewage Treatment Plant." In the discussion, an operator made a comment somewhat as follows: "If the people in our town only knew about some of the problems that we operators have to solve." This was an expression of a feeling familiar to all of us, namely, that the public is profoundly ignorant of matters pertaining to sanitary engineering.

An example of public attitude was observed when a member of our staff recently had occasion to call a plumber to his house. In the conversation, the plumber asked, "After all, was that project really necessary?" As operators, we have all directly or indirectly heard comments of this kind.

A common misconception regarding the sewage treatment plant was illustrated when we recently had occasion to purchase a piece of office equipment. The salesman went to a local banker for a testimonial letter regarding the equipment. Having written the letter, the banker asked the salesman where he was going to use it. Upon being informed that the letter would be used at the sewage treatment works, the banker exclaimed, "Oh, do they have an office down there?" Many people probably think of the treatment works as an old dirty tank with a sewer running into it and a dirty pipe running out, all located somewhere around the city dump.

These incidents and the similar questions and comments which come to all of us, illustrate the ignorance of the public regarding matters pertaining to sanitary engineering, the general lack of appreciation of the needs for and benefits derived from sewerage projects, and the lack of conception of the nature of sewage treatment plants, processes, and the problems of operation. It is not strange that the public often object to expenditure of money for sanitary works, that they criticize projects as needless waste, that they blame treatment works for imaginary odors, and that they think of the plant as a place to be carefully avoided.

This situation with its resultant handicap to sewerage projects directs our attention first to the question whether there is reason to do anything about it. Justification for expenditure of time and effort in this problem must be found in benefit to the public. If activities can be directed toward promotion of needed projects, and a better understanding of

* Presented at the Thirteenth Annual Meeting of the New York State Sewage Works Association, New York City, Jan. 16–18, 1941.

what they are and what they accomplish, general welfare will be promoted and all those engaged in the work will profit. The gain will be indirect, but none the less real.

The fact that sewage treatment plants and other sanitary works are essential to public health and are public projects supported by public funds, makes it essential that they have public support. From this standpoint there is justification for efforts directed toward informing or educating of the public regarding the needs for, and accomplishments of, sanitary engineering works.

It is also important that, after these projects are built, there be a fair attitude toward them both on the part of the public and public officials. This will tend to promote adequate support of the projects and to eliminate unfair criticisms with their attendant irritations and loss of time and effort in answering unjustified complaints. Indirectly there will result improved management, including employment of qualified personnel, and more efficient operation.

It may not be going too far astray to refer to this matter of educating the public in a more general way. The expression "the democratic way of living" has been used considerably of late. It is submitted that the success of the "democratic way of living" depends fundamentally upon an intelligent electorate. Citizens must know enough about public affairs, including public works of this nature, to be able to vote intelligently, and to give support where it is deserved and needed. We may, therefore, properly consider it our duty as public servants to promote such relations as will properly inform the taxpayers regarding the work under our direction.

With a situation before us which needs improvement and with justification for effort towards that improvement, we may now consider what can be done, and how it can be done. It is fitting, also, to look for some precedent.

First of all, it appears that one outstanding feature of successful contacts with the public is the attitude of those engaged in the work. Utilities call the work "public relations" and establish departments to carry it on. It is suggested, therefore, that our first step is to make ourselves public relations minded. This attitude must be continually borne in mind as a guide to our efforts.

Precedent for public relations activities is not lacking. Glancing through technical journals for the last year we find in *Electrical World,* one article entitled, "Selling a Rate Cut," and another one on "Human Relations Smooth Public Relations"; in *Power Plant Engineering* an article on "Customer Relations"; two articles in the *Journal of the American Water Works Association;* and in *Water Works and Sewerage* a paper entitled "Good Public Relations—the No. 1 Asset." It will be noted that those papers discuss public relations in the power and water supply utilities. Many of them discuss the contacts which the officials and employees of the utilities have with their customers.

Although this direct contact is lacking in the utility of sewage treatment, it does not follow that relations with the public should be ignored.

The handicap of these adverse circumstances requires, perhaps, more than the average of attention and effort on the part of sanitary engineers, and operators. We must take our story to the public, and give them information and a conception of our work which will result in an appreciation of the benefits, the problems, and the accomplishments of the profession.

Precedent within our own field of sanitary engineering is not entirely lacking. The author remembers the successful efforts of the late Gus Radebaugh, at Urbana-Campaign, Illinois, in the building of the sewerage project in those cities in 1923 and 1924. During the construction, the general public was invited to visit the work and signs were erected along the streets and highways, directing visitors to the plant. When the construction was finished, a dedication ceremony was staged with a formal program including speakers, unveiling of a memorial and participation by the public in the starting of plant equipment. Representatives of the Rotary Club were assigned to pull certain stop logs; a group from another organization took part in opening certain valves; the president of the Women's Club pushed the button which started the main pump. Throughout the operation of starting the plant, duties were assigned to representatives of the various groups. The result was that not only were these representatives and a reasonable number of the membership of these groups present at the ceremony but all those who took part felt that they knew something about the plant and that it, in part, belonged to them, as in fact it actually did. At Aurora, Illinois, Mr. Walter A. Sperry has for some years made special effort to make the citizens of that city welcome and interested in the sewage treatment plant. He displays at the entrance to the plant diagrams, models and descriptive material which portray in popular terms, the processes which the visitor will see in his trip about the treatment works.

There are, undoubtedly, a number of other plants where special effort has been put forth to welcome the public and to build up friendly relations with the public. Dedication ceremonies have been held at New York City, Watervliet, and Buffalo in New York State, and at a number of plants in other states. The work of Morris Cohn is well known, both in connection with the Schenectady plant and with his editorship of *Sewage Works Engineering*. All of us have had some occasion to meet the public. The question to be discussed now is how we may promote more contacts with the public and make those contacts more effective in creating favorable relations between the public and the sanitary engineering personnel.

It must be borne in mind that the actual work for any particular plant must be carried on by the plant personnel or management, or both. Assistance may be rendered by the Association or its committees, but it is essential that individual superintendents and operators become public relations minded and assume the burden of their local public relations work.

A few items in this work are obviously essential. It is not necessary to emphasize that the first and most important thing is to keep the plant clean and attractive in appearance; buildings and equipment must be clean, orderly, and well painted; the grounds should be attractively landscaped. Finding these conditions, the visitor is often pleasantly surprised at the park-like environment and becomes favorably impressed with the pride which the operating staff takes in the performance of their duty. He is likely to lose his resentment at paying the small bill for the service and may even develop a civic pride in the project.

Special effort should be made to let the public know that they are welcome at the treatment works. This can be done by displaying direction signs along the highway worded to catch the interest of the traveler and to express welcome to the visitor. Upon arriving at the plant the visitor should be made to feel that the operator and the management are glad to see him and appreciate his interest. Questions should be courteously answered and the interesting features shown.

To make the visit interesting the operator or other persons designated as guide should have a story to tell. This will vary somewhat with the interest of the different visitors; for example, the layman is interested in generalities, in what the equipment does and how it works, and in some of the more popular conceptions of quantities involved. Technical people, and particularly technical groups, will be more interested in bases of design, some of the theories of sewage treatment and the more technical features of the particular plant.

Visiting the treatment works is probably the most effective method of spreading information regarding sanitary work and for arousing a fair and favorable public interest in the local sewage treatment project. It is, therefore, worthwhile to exert some special effort to encourage visits to the plant. It may be well for example to establish visiting hours, such as Saturday and Sunday afternoons. These visiting hours can be made known and the plant staff can be particularly prepared at those times to escort visitors and make them feel welcome.

Another effective procedure is to issue special invitations to the various civic organizations and groups of the city. These invitations should be specific and personal rather than casual. The interest can be solicited of one or more officers of a group who will arrange the visiting trip. A definite appointment should then be made and guides provided who can best meet the interest of the group. The extra effort will be well repaid in appreciation on the part of the visitors.

Among groups thus invited may be included Boy Scouts, Girl Scouts and classes from schools and colleges. That is one way to reach the adults. In one Scout visit recently at Buffalo, an invitation was extended to the fathers and there were about as many adults as boys in the group. At the Buffalo plant during the last year, out of a total of 47 groups, there were 18 Boy Scout troops. The appreciation expressed by adults connected with these troops has been gratifying.

Another suggestion is to hold an open house at which a special invitation may be issued for a visit by the general public. In the December 19th issue of *Engineering News Record,* was a brief news item telling of an open house held by the city of Santa Paula, California, at its sewage disposal works to celebrate the completion of the first year of operation. It is suggested that an open house once a year might be effective and worthwhile.

There are certain items which can be made the subject of releases to the local newspapers. At the time of making the annual report, a brief discussion of quantities handled and results obtained may be published locally. The visits of local organizations and groups and also visits of out-of-town people, particularly those who are professionally interested in sanitary work may be covered by news items. In many of these releases paragraphs can be inserted which will be instructive as well as interesting to the readers.

The activities just described briefly are those which must be carried on largely by the superintendents, the management or the operators of the sewage treatment works. Another activity is that which may be carried on by a committee of the New York State Sewage Works Association. Following the Olean meeting of October, 1939, the New York State Sewage Works Association appointed a Public Relations Committee which is closing its first year of existence. The proposed objectives of this Committee are:

1. To promote education of the public on matters pertaining to sewage treatment.
2. To improve relations between the public and the operator.
3. To promote proper publicity of the activities and accomplishments of treatment works and personnel.

These objectives are somewhat abstract, but they indicate the goal towards which the work of the committee may be directed and serve as yardsticks for measuring and checking committee activities.

The committee has also suggested certain specific activities intended to promote the general cause of better public relations and to render assistance to plant personnel in their efforts toward better public relations. These specific activities have been outlined as:

1. To act as a clearing house to assist operators and other members of the Association in public relations work.
2. To furnish specific publicity for sewage treatment projects and for particular occasions.
3. To provide papers and discussions on the subject of public relations at the various conventions.

In acting as a clearing house for operators and other association members, it is thought that the committee can gather and compile information and data from the membership and from others which can be used to assist in public relations work. Members will be encouraged to communicate with the committee on matters of this kind or any other questions relating to public relations if they think the committee can be of assistance.

Specific publicity could be furnished by the committee for cities where a sewage treatment project is being contemplated. For example, a well organized plan of public education is often helpful in passing a referendum. Assistance might also be rendered in arranging dedication ceremonies, in preparing exhibits and displays, and on any other occasion where good presentation of the subject to the public may be essential or helpful.

An intangible but, nevertheless, important item in this work is to make operators and association members public relations minded. For this reason the committee considers it one of its proper functions to provide papers and lead discussions at conventions on the subject of public relations.

During the past year the committee, in cooperation with the officers of the Western Section of the New York State Sewage Works Association, has obtained some favorable publicity for association activities. For the fall meeting of this section held at Westfield in September, 1940, a news item was published in the *Westfield Republican* announcing the meeting. Included in the news item was a paragraph briefly mentioning the New York State Sewage Works Association and the importance of the sanitary work being carried on by its members. Following the meeting another news item was published describing the meeting and closing with a short paragraph complimentary to the local plant.

At the December meeting of the Western New York Section a reporter was present, giving the meeting similar favorable recognition. Interest in public relations within the Section was evidenced by the delivery of a paper on the subject followed by a lively discussion lasting almost an hour.

In answer, then, to the operator's comment, "If the people in our town only knew about some of the problems that we operators have to solve," we find that something can be done. The lack of information on the part of the public in regard to sanitary engineering in general and sewage treatment in particular, with its attendant criticisms, irritations and actual handicaps to progress, is a challenge to our profession. Let us accept this challenge. As operators, sanitary engineers, and as members of the Sewage Works Association, let us make ourselves public relations minded, and then proceed, with such help as may be rendered by Association committees, to improve our relations with the public. We will, thus, be doing a real service to the profession and to the public which the profession serves.

OBSERVATIONS ON OPERATION OF THE ACTIVATED SLUDGE PLANT AT MARLBORO, NEW JERSEY

By G. M. Ridenour

Associate, Dept. Water and Sewage Research, New Brunswick, N. J.

Results of the treatment of sewage by the activated sludge process at the Marlboro, N. J., sewage plant have been reported in previous papers, with emphasis on special operating studies. Data have recently been compiled on plant operation over a more extended period, from 1933 to 1937 inclusive, with special emphasis on (*a*) yearly variations in operation results and (*b*) the interrelation of different indices of purification and sludge density. The data are herewith given with some observations from the operator's viewpoint.

Description of Plant and Sewage

The treatment plant has been described in detail in previous papers.[1, 2] In general, the plant consists of a screen chamber, preliminary settling tank, three aeration units operable either in parallel or

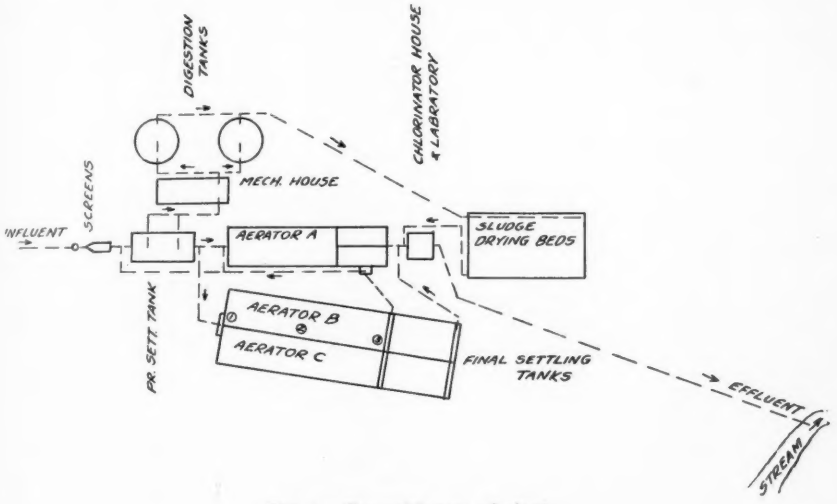


Fig. 1.—General layout of plant.

in series, final settling tank, separate sludge digestion, glass-covered drying beds and chlorination. A diagrammatic sketch of the plant is given in Fig. 1. The aerations units, of particular concern to these studies, consist of tanks 15 ft. wide by 15 ft. deep by 75 ft. long. Aeration is provided by either mechanical surface aeration with brushes, or by compressed air through porous tubes, or by both.

* Journal Series Paper, N. J. Agricultural Experiment Station, Department of Water and Sewage Research, New Brunswick, N. J.

The raw sewage received at the plant is a fresh, medium strength, domestic sewage, with average results of analysis as follows:

	Parts per Million
Suspended Solids	160
Total Solids	620
Ether Soluble	52
B.O.D.	240
Total Alkalinity	125
Chlorides	23
pH	7.2
Settleable Solids	4.8 c.c. per liter

The quantity of sewage varies from 420,000 to 530,000 gallons per day. Rates of flow during the day may, however, reach a maximum of 1,000,000 gallons and drop to a minimum of 120,000 gallons per 24 hours.

Total average theoretical detention time in the aerators varies between 13 and 17 hours.

Method of Operation

The manner of operation of the plant has been varied over the several years (see Fig. 3.) From June, 1933, until August, 1934, all aeration tanks were operated in parallel, with one unit mechanically aerated by means of surface brushes; the other aerated by compressed air through porous tubes. From August, 1934, until March, 1936, the tanks

Table I.—*Average Yearly Purification Through Activated Sludge Units*

Year	B.O.D.			Susp. Solids			NH_3-N	NO_3-N	D.O.	Aerator Solids		
	P.P.M. Inf.	P.P.M. Eff.	% Red.	P.P.M. Inf.	P.P.M. Eff.	% Red.	P.P.M. Eff.	P.P.M. Eff.	P.P.M. Eff.	P.P.M.	Settling Index	% Ash
1933	222	10	95.8	133	12	91.0	2.4	12.6	4.2	1800	6.8	27.4
1934	141	5	96.4	107	6	94.4	9.3	2.4	1.9	2000	6.8	20.0
1935	150	3	98.1	115	8	93.0	5.5	2.6	1.9	2200	7.6	21.7
1936	182	8	95.6	143	9	93.0	4.3	3.8	1.5	1350	3.6	16.8
1937	227	6	97.4	139	9	93.6	1.8	7.7	2.0	969	3.9	16.6
Ave.	184	6	96.6	125	9	93.0	4.3	5.8	2.3	1660	5.7	20.5

were operated in parallel with compressed air only in all tanks. Beginning March, 1936, and ending October, 1936, the tanks were operated in parallel with combined mechanical and compressed aeration. In October, 1936, this operation was changed to series operation consisting of single passage through one aerator followed by two aerators in parallel. During this period the single aerator was used primarily as a pre-aeration tank preceding conventional activated sludge treatment. Aeration was accomplished by combined mechanical and compressed air; the former by brushes and the latter by porous tubes. This same method of operation has been continued to date, with the exception that

pre-chlorination of sewage, and chlorination of return sludge [3] has been practiced intermittently since December, 1937.

General Purification Results

Average yearly overall purification results from the plant are given in Table I and Fig. 2 over a period from 1933 to 1937 inclusive. These results are general and represent an average of all conditions of plant operation during that period.

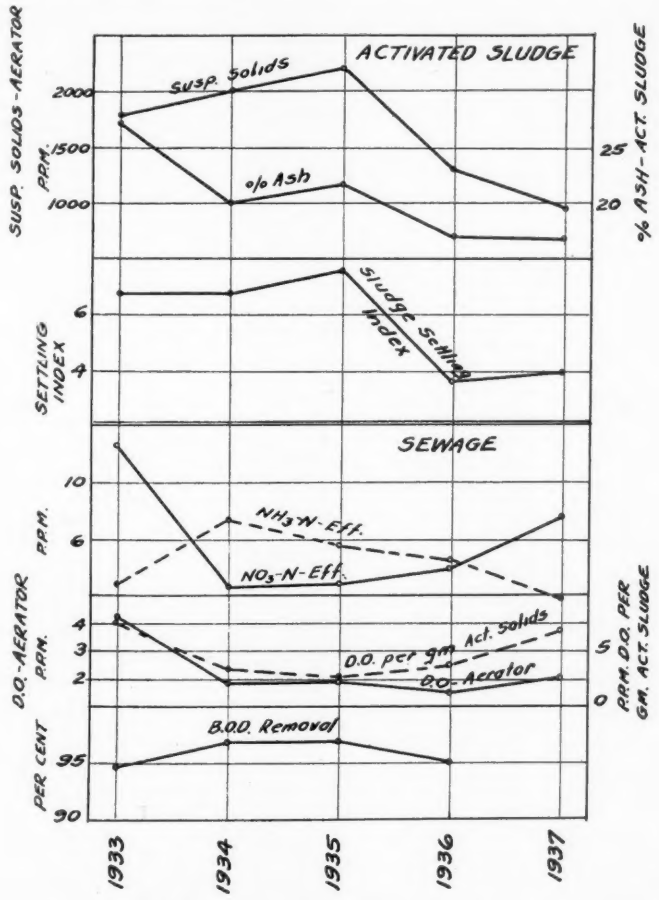


FIG. 2.—Average yearly operation results.

Table II represents progressive purification results through the aeration units of the plant over a similar period, exclusive of primary and final settling units. Point No. 1 in this table was located at the inlet end of the aeration tanks immediately after the raw sewage and return sludge were mixed; Point No. 2, in the middle; and Point No. 3,

TABLE II.—*Purification at Progressive Points Through Aerators*

Year	*B.O.D.						Turbidity, P.P.M.			NO_2-N, P.P.M.			D.O., P.P.M.			NH_3-N						Activated Sludge, P.P.M.
	No. 1	% Red.	No. 2	% Red.	No. 3	% Red.	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	% Red.	No. 2	% Red.	No. 3	% Red.	
1933	20	91.0	20	91.0	12	95.5	33	26	23	11.0	12.1	14.0	1.3	3.3	3.3	4	69.2	2	84.4	1	91.2	1800
1934	9	94.4	4	97.1	4	97.1	14	11	9	1.7	3.0	3.5	0.7	0.9	1.3	7	30.0	5	50.0	4	60.0	2000
1935	13	91.6	4	97.3	3	97.3	16	5	5	1.0	1.6	2.3	0.7	1.0	1.1	9	11.0	8	19.0	7	35.2	2200
1936	25	86.4	10	95.2	9	95.2	16	5	5	1.3	2.8	3.9	0.5	0.8	0.9	9	29.8	8	37.6	6	53.1	1350
1937							13	6	5	5.7	8.5	8.4	0.4	0.9	1.5	7	32.6	4	61.4	2	80.8	969
Ave.	16	90.8	9	95.1	7	96.3	18	10	9	4.1	5.6	6.4	0.7	1.4	1.6	9	34.5	5	50.5	4	64.1	1660

* See Fig. 1 for location of sampling points.

at the outlet end of the tanks immediately before the mixture entered the final settling units. The locations of these sampling points represent theoretical detention periods of approximately 5 minutes, 7 hours, and 14 hours, respectively. Tests were made on the supernatant liquor of the activated sludge mixture after ½ hour settling.

TABLE III.—*Activated Sludge*

Year	Suspended Solids				Volume—c. cs. Sludge Per Liter			Settling Ratio of Sludge (Sludge Index)			Return Sludge	
	Susp. Sol. Influent	Ash	Susp. Sol. Aerator	Ash	10 Min.	20 Min.	30 Min.	10 Min.	20 Min.	30 Min.	Susp. Sol.	Conc.
	P.P.M.	%	P.P.M.	%							P.P.M.	
1933.....	133	16.0	1807	27.4	558	498	457	4.8	5.9	6.8	4440	2.6
1934.....	107	25.0	2019	20.0	553	430	364	4.6	5.9	6.8	6170	2.9
1935.....	115	29.1	2205	21.7	532	419	360	5.1	6 4	7.6	5870	2.6
1936.....	143	26.5	1355	16.8	659	552	503	2.7	3.3	3.6	2762	2.0
1937.....	139	25.3	969	16.6	429	315	264	2.5	3 4	4.0	2580	2.5

In Table III, data are given to show the average yearly operating characteristics of the activated sludge with respect to quantity, volume, volatile content and settlability. "Volume of sludge" in the table gives the cubic centimeters of sludge volume per liter of sludge mixture after ½ hour settling. "Sludge index" is the ratio of weight of sludge in p.p.m. to the liter volume occupied after ½ hour settling or milligrams of sludge per c.c. volume. Increase in sludge index denotes a heavier sludge; a decrease, a lighter or bulkier sludge.

In Figs. 4, 5, and 6 and in Table IV, the data have been arranged to show what relation, if any, existed between purification, sludge settling, and temperature, and other operation indices obtained under practical operating conditions.

DISCUSSION

Sewage Purification.—Specific conclusions drawn from general operation averages are hazardous at best. This is particularly true in the activated sludge process where individual components of averages may

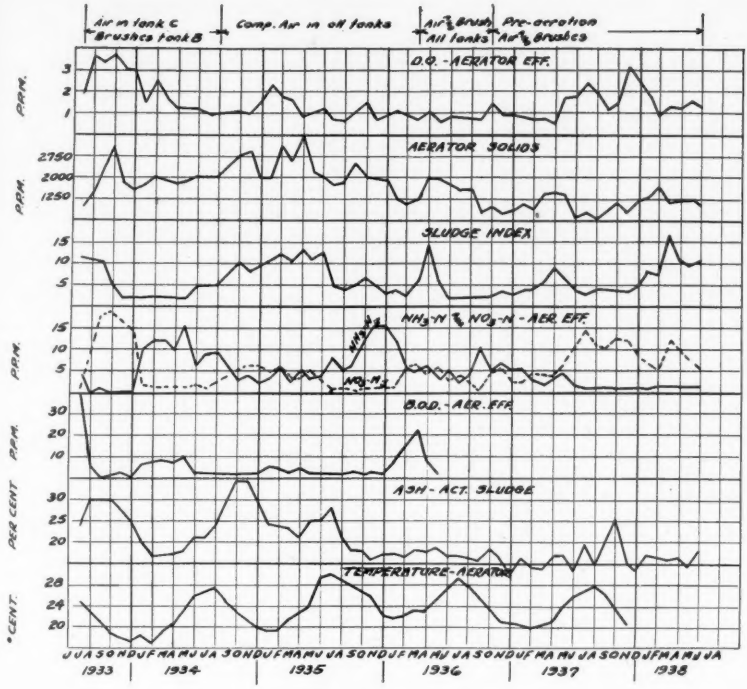

Air in tank C
Brushes took B
Comp. Air in all tanks
Air & Brush
All tanks Air & Brushes
Pre-aeration
D.O. - AERATOR EFF.
AERATOR SOLIDS
SLUDGE INDEX
NH3-N & NO3-N - AER. EFF.
B.O.D. - AER. EFF.
ASH - ACT. SLUDGE
TEMPERATURE - AERATOR
P.P.M.
PER CENT
°CENT.
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
1933
1934
1935
1936
1937
1938

FIG. 3.—Average monthly operation results.

vary over a wide range. It is assumed to be permissible in this case, however, to make some general observations by virtue of the large amount of data obtained and the relatively long period of operation.

Quantity of Activated Solids.—The relation between quantity of aerator solids and sewage purification indices is shown in Table I and

TABLE IV.—*Effect of Temperature—Winter and Summer Conditions*

Year	Activated Sludge						Purification Indices at No. 3									
	Settling Ratio		Act. Solids		Ash		Temp.		B.O.D.		D.O.		NO_3		NH_3	
	P.P.M. c.c.		P.P.M.		Per Cent		°C.		P.P.M.		P.P.M.		P.P.M.		P.P.M.	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1933	11.0	1.9	1478	1724	28.3	19.4		18	3	6	3.0	2.2	11.2	4.6	2	8
1934	4.6	10.5	2053	2367	21.0	25.5	27	20	3	3	1.0	1.7	1.4	4.9	8	3
1935	6.2	3.7	1943	1305	23.1	17.3	29	22	2	10	0.9	0.9	1.0	3.5	6	10
1936	1.9	3.6	1530	1040	16.4	14.2	27	20	5	—	0.7	0.8	2.5	3.1	5	4
1937	3.5	9.2	940	1299	17.9	15.6	26	19	—	—	1.7	1.6	11.5	7.8	1	1
Av.	5.4	5.8	1588	1547	21.3	18.4	27	20	3	6	1.4	1.4	5.5	4.8	4.4	5.2

in Figs. 2 and 3. On the basis of these figures it appears that with respect to reduction in B.O.D. and suspended solids the sewage purification was practically equal for all quantities of solids between 960 and 2200 p.p.m. It is also evident that as long as a minimum critical quantity of dissolved oxygen was maintained in the aerator, the reductions in ammonia and the quantity of nitrates formed were approximately the same for both the higher and the lower quantities of aerator solids. The major result of varying the quantity of solids was the effect on residual dissolved oxygen in the aeration mixture. Higher values of activated sludge taxed the capacity of aeration devices to such an extent that the higher stages of oxidation were suppressed, as indicated by the NH_3–N and NO_3–N values.

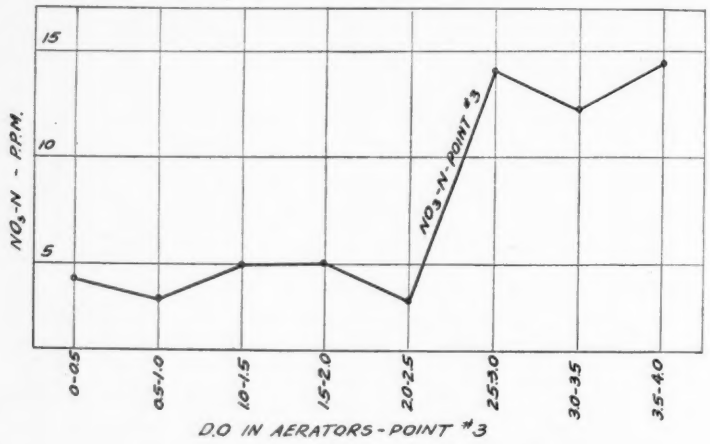


FIG. 4.—Relation between D.O. and nitrification.

Dissolved Oxygen.—The effect of dissolved oxygen tension on sewage purification can be observed from the data in Table I and in Figs. 2 and 4. It will be seen that B.O.D. reduction varies more or less inversely with the dissolved oxygen reduction, if small differences are considered. It is quite noticeable, however, that per cent removal in B.O.D. is in no way proportional to the residual oxygen. This is quite definite in Fig. 3 where both high and low B.O.D. values in the supernatant liquor of the aerator effluent occurred with both high and low residual dissolved oxygen, and in Table II where residual dissolved oxygen values as low as 0.5 to 0.7 p.p.m. gave B.O.D. removals as high as 86 to 91 per cent at the inlet end of the aerator.

The effects of high or low D.O. values were most noticeable in NH_3–N reduction and in NO_3–N formation. In Fig. 2, there is a distinct similarity of trend between D.O. and NO_3–N as well as an inverse relation between D.O. and NH_3–N. This relation also clearly shows in Fig. 3 and particularly in Fig. 4 where data are compiled to show nitrate-nitrogen values corresponding to the residual D.O. in the aerators.

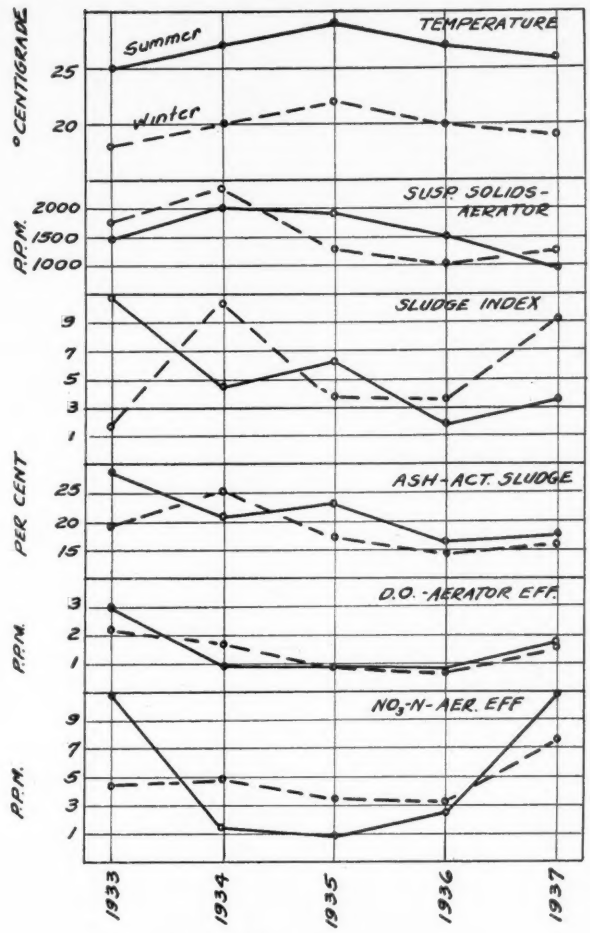


FIG. 5.—Effect of temperature.

Rather uniform nitrification took place with dissolved oxygen values between 0.5 and 2.0 p.p.m. When dissolved oxygen was higher a rapid increase in nitrification was apparent. The value of this increase in nitrates is necessarily related to time of aeration as well as quantity of D.O. In this case the detention time in the aerators was long. A D.O. of 2.0 p.p.m. with a theoretical detention time of 6 hours might not exhibit this phenomenon.

Winter and Summer Temperature Effects.—The effects of winter and summer temperature conditions on the purification and sludge settling processes are shown in Table IV and Fig. 5. The effect of varying temperatures on biological purification processes is well known. It is interesting to note this influence over the practical range of temperatures encountered at this plant.

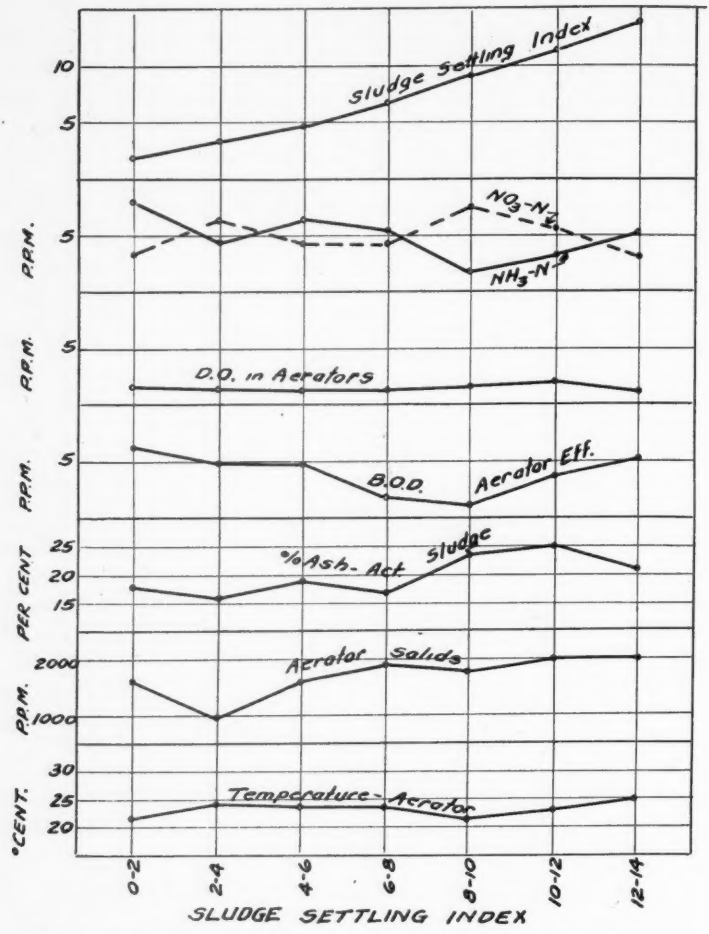


FIG. 6.—Relation between density of solids and other operation indices.

Over the five-year period of operation the lowest yearly average minimum winter sewage temperature was 18° C. (= 64° F.). Maximum summer temperature average was 29° C. (= 84° F.). The average differential between average winter and summer temperatures was 11° C. or 20° F.

Reference to the five-year averages in Table IV shows that the differences in purification results for summer and winter conditions with the above temperature differentials were practically negligible. The slight differences that did exist were, however, in the direction that would be anticipated in the process, namely, increased rate of biological activity with increased temperature. This is indicated by slightly smaller remaining B.O.D. and NH_3–N values, and greater NO_3–N values in the aeration tank effluent.

The differences in these values were so small, however, as to be of insignificant practical effect. In fact, reference to individual years will show that in 1934 and 1936 the degree of purification was slightly greater in winter than in summer, indicating the more predominant effects of other operating factors present in normal plant operation.

An interesting point that might be noted is the uniformity of residual dissolved oxygen values during the two seasons. It would normally be expected that during the colder winter periods, with the correspondingly greater oxygen solubility values, greater residual values should be found in the aerators. With the exception of one year, however (1933), the D.O. values in the aerators were remarkedly constant.

The greatest differences in winter and summer results are indicated in the ash content of the activated sludge. As would be theoretically expected, the percentage ash of the sludge was consistently greater during the summer period (21.3 per cent) than during the winter (18.4 per cent).

The effect of winter and summer temperature was negligible on the settling characteristics of the sludge. The sludge index averaged 5.4 in summer and 5.8 in winter. The average minimum winter temperature of the sewage was, however, comparatively high (62° F.) which may account for smaller differences than might have been expected. Individual yearly averages show that high or low settling rates occurred both in winter or summer.

Ash of Activated Solids.—The ash content of the aerator solids has varied over a rather wide range during the five years of operation. Since the beginning of the period, the ash of the sludge has shown a tendency to decrease from a maximum average value of 27.4 per cent in the initial period to 16.6 per cent in the last year of operation. This latter value is generally considered as below that normally expected in the sludge from an activated sludge plant. Experiences at this plant have served to indicate, however, that ash content cannot be correlated in any practical magnitude with other indices of aerator performance. As far as practical results are concerned, good reduction in B.O.D., suspended solids and NH_3–N can be secured with either high or low ash sludge. Large quantities of nitrate have been secured with either high or low ash. On the basis of average yearly results, there appears to be some relation in trend between the ash of the sludge and density of settleability of the sludge. This tendency is, however, not proportionate, and inspection of the more detailed data in Fig. 3 shows that over considerable periods that relationship fails to hold.

Progressive Purification Through Aerators.—Progressive purification results through the aerators given in Table II for the five year operation period show some general typical characteristics. An average of 90.8 per cent of the biochemical oxygen demand was removed from the sewage liquor at the inlet end of the aerator representing a theoretical minimum of five minutes and a maximum of one half hour detention period in the aerators. The remaining period of aeration

was responsible for only 5.5 per cent additional removal. Coincidentally, NH_3–N reduction at the first point amounted to 34.5 per cent with an additional reduction of 29.6 per cent through the remainder of the aerator, giving a total removal of 64.1 per cent. At the inlet end the nitrate present in the return sludge-sewage mixture amounted to 4.1 p.p.m. after five minutes aeration, with an additional increase through the aerators of 2.3 p.p.m. or a total of 6.4 p.p.m. In contrast to the relatively uniform reduction in B.O.D. at the inlet, the NH_3–N and NO_3–N present fluctuated over a wide range. Ammonia reduction at the inlet varied from 11.0 to 69.2 per cent. Nitrates were present between a minimum of 1.0 p.p.m. and a maximum of 11.0 p.p.m. These fluctuations can probably be accounted for by the varying nitrates in the return sludge. Rates of change through the aerator were likewise dissimilar in different years. It should be noted that during the year 1933, with high nitrates at the inlet end and through the aerator, the dissolved oxygen in the aerators was considerably higher than that of other years. These progressive purification results also show the comparative immunity of B.O.D. removal to the influences of ordinary changes in operating conditions, which, however, are sufficiently great to affect the higher stages of oxidation.

Settling of Activated Sludge.—The settling characteristics of the activated sludge are shown in Fig. 6, where a statistical grouping of sludge densities has been plotted against other operation indices. The only index in this figure which possibly seems to be related to the sludge settling index is the ash of the activated sludge. This relation fails to hold, however, when an inspection is made of Fig. 3, where settling ratios have run counter to ash values during many periods of operation. High and low ratios have been obtained under conditions of either a high or a low degree of purification of sewage or high or low temperature conditions.

General Observations

Operating observations at this plant over a period of several years have led to a number of practical conclusions with respect to sewage purification by activated sludge and the settling characteristics of the sludge floc. Some of these observations may seem at variance with certain fundamental theories which have been advanced on the process. As a matter of fact, the inconsistency with theory may be only apparent, because of the greater proportionate effect of other factors that are of importance to practical plant operation. The plant operator sees the value of a theory only so far as this theory is subject to application and control toward a certain objective. The theory must also be of enough vitality to the process to exert an effect of such magnitude that practical operating influences will not make the theory ineffective in producing results. The observations that follow are a few from an operator's viewpoint only.

Purification of Sewage.—Purification of sewage with respect to reduction in biochemical oxygen demand and suspended solids can be ac-

complished with comparatively little trouble by the activated sludge process. The quantities of activated solids used for this purpose may vary over a wide range with practically equal results. There is, however, a more or less critical quantity below which sewage purification is impaired. The reduction in purification below this critical value is not proportionate to the decrease in quantity of solids. The increase in purification by use of solids above the critical quantity does not justify the increased cost of the additional air required to maintain aerobic conditions under that condition.

Good reduction in biochemical oxygen demand and suspended solids can be effected without high nitrification of the sewage. Clarification of the sewage and reduction in B.O.D. seem in large part to be almost immediate, provided aerobic conditions are maintained and the critical minimum quantity of activated solids is mixed with the untreated sewage.

The nitrification of the sewage liquor appears to be strictly related to the dissolved oxygen present in the aerators up to a certain D.O. residual. This latter residual indicates the value of dissolved oxygen above and below which complete aerobiosis is or is not maintained in the aerators. The exact critical D.O. value for aerobic conditions throughout the entire contents of the aerator will depend on the specific situation with respect to hydraulic characteristics of mixing and diffusion of air.

Excellent reduction in B.O.D. and suspended solids can result with very low residual oxygen values in the mixed aerator liquor. The influence of oxygen tension on removal of these materials does not seem important so long as aerobic conditions are maintained. The effect of oxygen tension does appear, however, to be a more certain function in the higher stages of oxidation, such as nitrification in the sewage, which bears a distinct relation to residual D.O. in the aerators.

Experiences indicate that residual D.O. values as usually determined do not always indicate the presence of aerobic conditions in the aerators. These residuals can, however, serve to indicate a critical point above and below which complete aerobiosis is maintained. This value will depend on the hydraulic characteristics of the aeration tanks.

The ash content of the activated sludge does not seem to be necessarily a function of good purification. High B.O.D. and suspended solids removal as well as high nitrification have been accomplished with either high or low ash values in the sludge. In fact, some of the best results in this respect have been obtained with sludges of very low ash content.

The effect of temperatures, in the ranges encountered in this study, appears to be of no practical importance in sewage purification. The higher temperatures of the summer do appear in mass studies to create higher ash values in the activated sludge, but beyond this no distinct relationships have been observed.

Sludge Settling.—From observations that have been made at this plant there seems to be lack of correlation between settling characteristics of the activated sludge with any other chemical or physical indices of plant operation.

Four general physical classifications of sludge have been observed: (1) a light-weight voluminous floc, capable of producing a clear sparkling effluent of high quality; (2) a similarly light-weight and voluminous floc which produces a high quality effluent but which contains visible straggling floc particles due to lack of clear-cut separation of sludge and liquor; (3) a dense, quick-settling and compact sludge that gives a good quality effluent and a clear-cut zone of separation between sludge and supernatant liquor; and (4) a quick-settling and dense sludge that lacks a clear-cut zone of separation and produces an effluent high in turbidity and low in quality.

The only index found to which sludge settling characteristics could possibly be related was the quantity of filamentous organisms in the activated sludge. *Sphaerotilus,* although never entirely absent, was always more predominant in the floc of low density and slow settling characteristics. Whether these filamentous growths are the cause or the result of environmental conditions that produce floc with varying densities has been a constant question. Some of the best effluents which have been turned out at this plant have been produced with a sludge floc which was seemingly entirely composed of filamentous growths. The disposal of this type of sludge floc, however, was a difficult problem.

Summary

Records of a five-year period of operation at the Marlboro, N. J., activated sludge plant have been compiled with special emphasis on (*a*) monthly and yearly variations in purification results and (*b*) the interrelation of different indices of purification and sludge density.

From these records and the more detailed experiences and studies made during the same period, some general observations have been drawn. These are:

(*a*) Biochemical oxygen demand and suspended solids are readily reduced in the sewage by the activated sludge process. Quantities of activated solids used in this respect varied over a wide range with equal results. There was a minimum critical quantity below which the purification of sewage was impaired. However, the reduction in purification was not proportionate to the decrease in quantity of activated solids.

(*b*) Good reduction in B.O.D. and suspended solids can be secured without high nitrification of the sewage, and without high dissolved oxygen residuals. However, high nitrification of the sewage is dependent on higher dissolved oxygen residuals.

(*c*) Experiences indicate that residual D.O. values as usually determined at a routine sampling point do not always indicate the presence of aerobic conditions throughout all parts of the aeration units. For a

given sampling point there will be a critical quantity of D.O. below which some parts of the unit may be anaerobic. This critical value depends on the hydraulic and air diffusion characteristics of the aerator. The maintenance of residual D.O. much above this critical value does not seem to bear any practical relation to the sewage purification.

(*d*) The amount of ash in the activated sludge does not seem to be a function of high purification. High B.O.D. and suspended solids reduction as well as high nitrification have resulted with either high or low ash sludges.

(*e*) Beyond a slight increase in the ash of the activated sludge in the summer, the comparatively narrow range between winter and summer temperatures had no effect on sewage purification or sludge density.

(*f*) No correlation was found between any chemical or physical indices of plant operation and settling characteristics of the activated sludge. The quantity of filamentous organisms was the only index that could be related to sludge settling.

(*g*) Good purification results were secured with a dense and quick-settling activated sludge. The best purification was obtained with the lighter and more voluminous sludge containing high concentration of Sphaerotilus. Disposal of this type of sludge was difficult, however, without the larger settling and digestion capacities required for sludge of this character.

Acknowledgment

The author expresses his appreciation to Mr. C. N. Henderson, of the Department of Water and Sewage Research, N. J. Agricultural Experiment Station, for assistance given in the analytical work necessary in connection with these data.

References

1. G. M. Ridenour and I. O. Lacy, "Activated Sludge Plant with Brush Aeration," *This Journal*, 4, 263–274 (March, 1932).
2. G. M. Ridenour and C. N. Henderson, "Comparison of Sewage Purification by Compressed Air and Mechanically Aerated Activated Sludge," *This Journal*, 8, 766–779 (September, 1936).
3. G. M. Ridenour, C. N. Henderson and H. B. Schulhoff, "Operation Experiences with Chlorination of Activated Sludge," *This Journal*, 9, 63–69 (January, 1937).

Stream Pollution

DISSOLVED OXYGEN AND B.O.D. DETERMINATIONS. THEIR APPLICATION AND INTERPRETATION *

By C. C. Ruchhoft

U. S. Public Health Service, Stream Pollution Investigations Station, Cincinnati, Ohio

The dissolved oxygen and biochemical oxygen demand determinations are important because of their wide application in evaluating sewage and industrial waste treatment plant efficiencies and studying pollution and natural purification in streams, lakes and harbors. The dissolved oxygen determination is undoubtedly the most valuable single chemical criterion available in the sanitary field. The principal uses for this determination may be listed as follows:

1. For activated sludge plant control.
2. For stream pollution studies.
   - (*a*) To determine whether oxygen conditions are satisfactory for aquatic life, the permissible lower limits for fish being 3.0 to 5.0 p.p.m.
   - (*b*) To determine oxygen depletion and follow the "oxygen sag curve" below principal points of pollution.
   - (*c*) In studies of reaeration rates, for these rates depend upon the oxygen saturation deficit.
   - (*d*) In studies of plant photosynthesis in lakes and streams.
3. For biochemical oxygen demand determinations and studies.

Such a variety of applications leads to the use of this determination on waters which frequently contain substances that interfere with the Winkler method for the dissolved oxygen test. This method, however, is the only practical and convenient method available, and consequently modified procedures designed to overcome the effects of various interfering materials have been developed.

The Winkler method depends upon the quantitative oxidation of manganous hydroxide to a higher form of hydroxide at high pH by the dissolved oxygen in the water. This complex form of manganese hydroxide liberates iodine from the potassium iodide when the mixture is acidified. The iodine is then titrated with standard thiosulfate solution and the original dissolved oxygen is calculated. This procedure is really applicable only to distilled and other very pure waters. Sulfites, sulfides, ferrous and ferric iron, nitrites and various forms of organic matter interfere and consequently the proper modified technique must be used if any of these are present.

* Presented at the Meeting of the Kansas Water and Sewage Works Association, Lawrence, Kans., March 14, 1941.

The alkaline hypochlorite [1] method should be applied to paper mill wastes to destroy sulfites and sulfides. When ferrous iron is encountered in quantities of over 1.0 p.p.m., the well known Rideal Stewart [1] method, which oxidizes the ferrous iron, should be used. If the sample contains both ferrous and ferric iron in considerable quantities (over 40 p.p.m.) the Rideal Stewart procedure, including also potassium fluoride, should be employed and the iodine should be titrated immediately following final acidification. This procedure following oxidation of ferrous iron binds the ferric iron in a complex molecule so that the titration can be completed without the release of appreciable amounts of iodine by the ferric iron.

Numerous forms of organic matter such as that in sewage, carbohydrates and peptones react directly with dissolved oxygen at the high pH of the Winkler determination and consequently low results are obtained. Sewage also lowers the dissolved oxygen result in proportion to its iodine demand. It is well known that the so-called short Winkler technique,[1] in which the period of alkalinization is shortened, is helpful though not completely effective in eliminating such interferences. Consequently, an alum precipitation technique [2] was developed. The alum precipitation procedure does not affect the dissolved oxygen content, but does remove much of the interfering material. A convenient sample (1,000 ml.) is dosed with alum solution and ammonium hydroxide and the precipitate is allowed to settle. The supernatant is then siphoned into the standard D.O. bottles and the short Winkler technique is applied. This procedure has been found most effective for raw sewage and river mud suspensions.

Dissolved Oxygen in Activated Sludge Liquors

The determination of dissolved oxygen in activated sludge aeration tank liquors is important for control of the process. These liquors contain not only large quantities of organic matter, but also an aerobic microflora so large that dissolved oxygen is utilized at very high rates. It is, therefore, most important to stop this biochemical oxygen utilization immediately and completely at the time the sample is collected for the oxygen determination. It has recently been found [3] in our laboratory that a mixture of sulfamic acid, acetic acid and copper sulfate is much more effective for stopping oxygen utilization in activated sludge liquors than the copper sulfate solution which is generally used in practice. When an activated sludge sample is collected in a bottle containing the effective dose * of the above inhibiting solution, the oxygen utilization is stopped, the nitrites are destroyed and the floc is coagulated so that the clear supernatant can be easily siphoned into a bottle for the D.O. determination. With this procedure, there was found to be practically no loss of dissolved oxygen in 30 minutes after the inhibitory solution was added. In a recent study of the operation

* Ten ml., per liter of sample, of a solution containing 50 grams of copper sulfate, 32 grams of sulfamic acid and 25 ml. of glacial acetic acid in one liter of distilled water.

of the activated sludge plant at the United States Public Health Service Hospital at Lexington, Kentucky, the procedure was very satisfactory and most useful.

Dissolved Oxygen in River Waters

The interfering material most frequently encountered in river water is nitrite. Quantities of more than .05 p.p.m. nitrite nitrogen interfere by catalytically releasing iodine near the end point of the titration. Consequently, high results are obtained in the presence of nitrite. To prevent this the nitrite must be destroyed. For this purpose, three satisfactory methods are available:

I. The Rideal Stewart, or permanganate modification.
II. The Alsterberg, or sodium azide modification.[4, 5, 6]
III. The sulfamic acid modification.[7]

The Rideal Stewart is the oldest of these, and has been mentioned already. As it also corrects the interference due to ferrous iron, its use is indicated for coal mine drainage and rivers containing acid iron wastes. Because of their dependability and simplicity, the second and third modifications are preferred on all rivers which contain nitrites, but less than 1.0 p.p.m. of ferrous iron. These modifications depend upon the following reactions to destroy nitrite.

1. Sodium azide and sulfuric acid.
   $NaN_3 + H_2SO_4 \rightarrow NaHSO_4 + HN_3$
   $HN_3 + HNO_2 \rightarrow H_2O + N_2 + N_2O$
2. Sulfamic acid.
   $H(NH_2)SO_3 + HNO_2 \rightarrow H_2O + N_2 + H_2SO_4$

The sodium azide may be applied in a preliminary acid treatment or combined with the alkaline iodide reagent as Alsterberg originally used it. Because of convenience and simplicity, its addition with the alkaline iodide solution is usually favored in practice. However, the preliminary azide treatment has an advantage on unknown samples in that a straw or reddish color is obtained if 40 p.p.m. or more of ferric iron are present. Using this color as a warning, potassium fluoride can also be added and precautions taken to titrate immediately after final acidification. In other words, this treatment automatically indicates the presence of ferric iron, so that with the proper precautions satisfactory results with as much as 200 p.p.m. of iron can be obtained.

The sulfamic acid can only be used as a preliminary treatment. However, sulfamic acid has advantages over sodium azide in cheapness, availability and non-poisonous nature. Either of the last two modifications can be best applied to the majority of surface waters and plant effluents that are known to be free of ferrous iron, but almost always contain small quantities of nitrite.

The Biochemical Oxygen Demand Test

In natural purification under aerobic conditions, the organic materials are oxidized by the microflora and fauna to simple end products. This process can be considered as taking place in two distinct stages. In the first stage, the complex organic materials are broken down. The carbonaceous matter is oxidized to carbon dioxide and humus while the nitrogenous material is broken down and the nitrogen not used for growth requirements is left as ammonia. A large variety of organisms play a part in this stage.

The second stage, in which the ammonia is oxidized to nitrites and nitrates, is presumed to take place after about 90 per cent of the carbonaceous material has been oxidized. Usually this occurs after 10 to 12 days but, under some conditions, it begins much earlier. In the activated sludge process, carbonaceous and nitrogenous oxidation may take place simultaneously within a few hours after sewage is added. The second, or nitrogenous, stage of oxidation is carried out by only two genera of bacteria.

The biochemical oxygen demand test is a direct adaptation of the natural purification reaction of polluted waters. Briefly, the test consists of a determination of the dissolved oxygen in each of two duplicate portions of sample, one before and the other after incubation at 20° C. usually for a period of 5 days. The difference in the oxygen content of these portions expressed in milligrams per liter is the biochemical oxygen demand of the sample for this period. Frequently samples must be diluted because of their high oxygen demand and because of the fact that the solubility of oxygen in water at 20° C. and 760 mm. is only 9.17 milligrams per liter. When the sample has been so diluted, the loss of oxygen of the diluted portion in milligrams per liter is multiplied by the dilution factor to obtain the oxygen demand of the sample.

To follow the course of the biochemical purification reaction, it is necessary to incubate a long series of similar sample portions and determine the oxygen loss at regular intervals up to 30 or 40 days. By this means the initial point of the second stage or nitrogen oxidation can be located and a better idea of the course of the oxidation reaction can be obtained.

Certain precautions must be observed in carrying out the B.O.D. test. Important among these are:

1. Clean glassware.
2. Accurate and uniform incubator temperature.
3. Tightly stoppered and properly sealed bottles.
4. Satisfactory dilution water.
5. Adjustment of dilutions to obtain adequate oxygen depletions.
6. Careful neutralization of toxic materials.
7. Proper seeding where necessary.
8. Inclusion of blank controls on dilution water and seed.
9. Selection of proper dissolved oxygen procedure.

A bicarbonate dilution water is recommended in the present standard method, but there has been some objection to its use because of its rather high initial pH and inability to withstand storage. A number of investigators have studied the dilution water problem. Holderby and Lea [8] have pointed out that if the carbon to nitrogen ratio is too high (greater than 6:1) low B.O.D. results are obtained. Lea and Nichols [9] showed that this difficulty, which was observed on paper-mill wastes, could be overcome by adding small amounts of ammonium sulfate to the dilution water. The addition of this salt to dilution waters would be desirable for such wastes and might not be objectionable in most sewage and polluted water work unless long time demands are to be obtained. With activated sludge effluents, however, high results are frequently obtained in five days as a result of the oxidation of the nitrogen added. The Standard Methods Committee of the Federation of Sewage Works Associations is now making a comparative study of bicarbonate water and the mineralized phosphate buffered water of Theriault, McNamee and Butterfield [10] with and without ammonium sulfate.

In regard to the neutralization of toxic materials, it would certainly seem advisable to neutralize the sample when the pH is below 5.0. It has been shown, however, that the B.O.D. reaction is carried on apparently by a special flora down to a pH of about 2.0, though nitrification was not demonstrated.[11] It has also been observed that if iron and aluminum salts are present in acid waters and the sample is neutralized and seeded, the precipitation of these salts carry down organic material with resulting B.O.D. values which are frequently lower than those obtained in the unneutralized sample. In such cases, this procedure indicates the B.O.D. of the water after chemical precipitation, but does not measure the organic load on the stream. To obtain the true measure of the organic load, a procedure of pH adjustment without chemical precipitation would be desirable and this problem is being studied.

Interpretation of the Results of the Oxygen Demand Test

The general form of the deoxygenation curve is shown in Fig. 1. Curves obtained at 9, 20 and 30° C. by Theriault [12] are presented. The abscissae are times in days and the ordinates are total quantities of oxygen used in the corresponding time intervals. Considering the curve for 20° C., a marked increase in rate of oxygen utilization is noted about the 14th day, indicating the start of the second stage of oxidation. At the higher temperature, the practical completion of the carbonaceous oxidation occurred earlier while at the lower temperature the completion of the carbonaceous oxidation was delayed and the second stage had not started at the end of the experiment. It has been established that the first stage oxidation reaction follows a definite mathematical rate.

The mathematical expression of this rate is very useful in the practical interpretation of the analytical results. It has been found that the

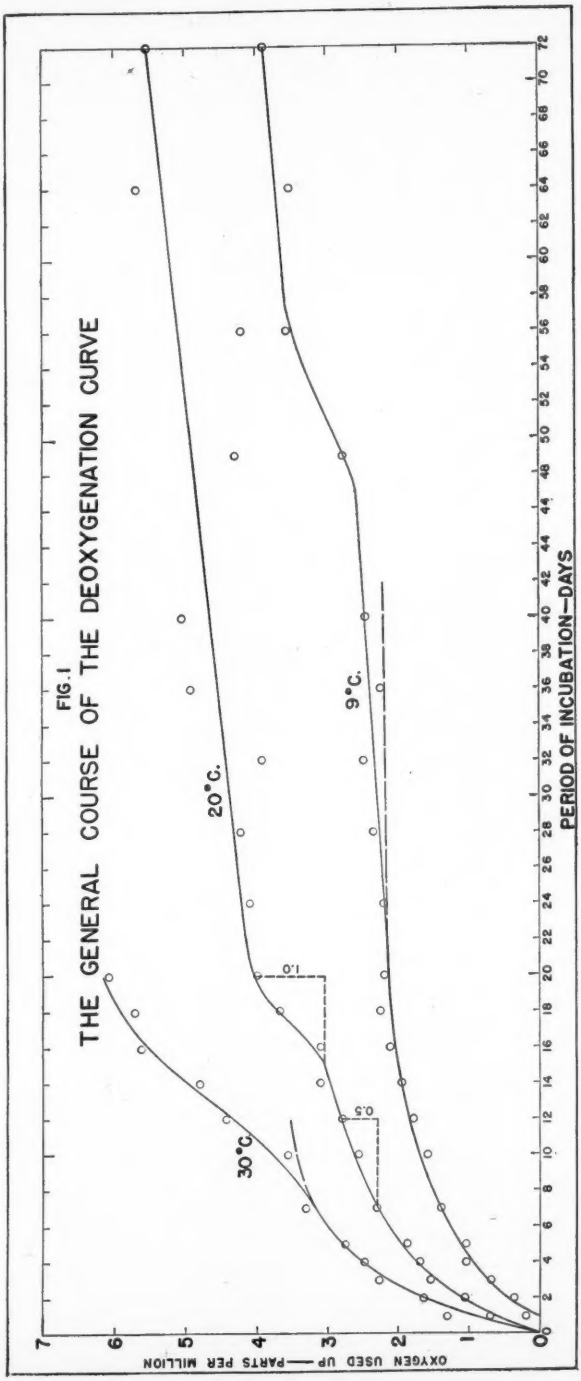


FIG. 1
THE GENERAL COURSE OF THE DEOXYGENATION CURVE
OXYGEN USED UP — PARTS PER MILLION
PERIOD OF INCUBATION—DAYS
30°C.
20°C.
9°C.
1.0
0.5
0
1
2
3
4
5
6
7
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72

rate of oxidation at any instant is directly proportional to the amount of oxidizable organic matter present in the sample. The mathematical expression for this when the organic matter is given in terms of oxygen demand is:

$$X_t = L(1 - 10^{-kt}) \tag{1}$$

where

X_t = the oxygen demand in t days
L = the total oxygen demand of the first stage
k = the deoxygenation velocity constant = 0.10 at 20° C.

It should be understood that this value of "k" applies only to dilutions of domestic sewage and will not hold for many industrial wastes or special materials. The deoxygenation velocity constant k varies with the temperature and can be calculated for any temperature from the relation

$$k_T = k_{20}(1.047^{T-20}) \tag{2}$$

where

k_T = deoxygenation velocity constant at T° C.
k_{20} = deoxygenation velocity constant at 20° C. = 0.10.

The total oxygen demand (L) for the first stage also varies with the temperature. The expression for this relationship is:

$$L_T = L_{20}(0.02T + 0.60) \tag{3}$$

where

L_T = value of L at T° C.
L_{20} = value of L at 20° C.

With the help of these three formulae the oxygen demand (first stage) of a sample for any temperature and any time period may be calculated from a laboratory oxygen demand test. Tables are available in the literature to assist in these calculations. Phelps [13] has presented a table of factors for the conversion of the 5-day B.O.D. at 20° C. to the demand for any other time and temperature. In the preparation of this table the change in total demand (L) for changes in temperature has been disregarded. However, this change is not great for small divergences from 20° C. and consequently for practical purposes these factors are very useful. Theriault [12] presented a series of tables of the values of the function $(1 - 10^{-kt})$ for incubation times up to 25 days and for various values of k from .040 to .250. Streeter [14] has contributed a table of the values of the deoxygenation velocity coefficient for all temperatures from 0 to 30° C. calculated from formula (2). Hoskins [15] has illustrated the oxygen demand computations using these three formulae and presented a table of factors for converting the B.O.D. for any time at 20° C. to any other time at the same temperature.

The course of the second stage or nitrogenous oxidation has not as yet been so well established. Mohlman, *et al* [16] have presented data on nitrogenous oxidation in the Illinois River. Streeter [14] found that the

following discontinuous equation gave excellent fitting with the Illinois River first and second stage oxidation curves.

$$Y = L_c(1 - 10^{-k_c t}) + L_n[1 - 10^{-k_n(t-a)}]$$

where

Y = the total B.O.D. oxidized up to any time (t),
L_c and L_n = the total first and second stage B.O.D., respectively,
k_c and k_n = the deoxygenation coefficients for the first and second stage, respectively,

and (a) = a lag constant indicating the time at which the second state begins.

In this analysis of the Illinois River data it was found that the oxidation rate for the second stage or nitrogenous oxidation was approximately one-third of the rate for the first stage oxidation, the mean values for k_c and k_n being .103 and .031, respectively.

B.O.D. Decrease in Streams

Though the oxidation of carbonaceous organic matter in streams follows the aforementioned expression with a k of 0.1 at 20° C., the rate of B.O.D. decrease may or may not do this. Streeter [14] has pointed out that a number of factors besides natural oxidation affect the progressive decrease of B.O.D. in a stream. Among these are tributary inflow, sedimentation, adsorption by attached bottom growths, effect of "immediate oxygen demand" and the occurrence of a transition from the first to the second stage of oxidation. All of these factors have been adequately discussed by Streeter. Additional work has shown that most of the so-called "immediate demand" that was observed on bottle tests of river deposits was an apparent oxygen loss due to use of the improper method for determining dissolved oxygen. It is true, however, that even with proper dissolved oxygen procedures there is a chemical demand which is satisfied at higher rates than normal.

Moore [17] of this laboratory has recently found that the "immediate demand" phenomenon is observed only after a sewage dilution has become septic or has been in contact with a septic mud. It is rather difficult to measure the "immediate demand." However, when a stream is depleted of oxygen, the effect of immediate demand will be noticed as the difference between the calculated and observed initial dissolved oxygen. As a matter of fact, "immediate demand" is a misnomer for it is actually satisfied within about 48 to 72 hours after the sample is aerated. At present, no effort is being made to determine the extent of the "immediate demand" in deoxygenated streams. This problem needs further study.

Because of the above mentioned five interfering factors, the natural biochemical oxidation constants should be applied with considerable caution in estimating B.O.D. reductions at various points on a stream.

Recent studies on the Scioto River by Kehr [18] have indicated rather definitely that the rates of B.O.D. decrease in a small stream bear no consistent relation to the natural deoxygenation rates.

BIBLIOGRAPHY

1. Standard Methods of Water Analysis, American Public Health Association, New York (1936).
2. C. C. Ruchhoft and W. Allan Moore, *Ind. Eng. Chem., Anal. Ed.*, **12**, 711 (1940).
3. C. C. Ruchhoft and O. R. Placak, paper in preparation (1941).
4. C. C. Ruchhoft, W. Allan Moore, and O. R. Placak, *Ind. Chem., Anal. Ed.*, **10**, 701 (1938).
5. G. R. Barnett and E. Hurwitz, *This Journal*, **11**, 781 (1939).
6. O. R. Placak and C. C. Ruchhoft, *Ind. Eng. Chem., Anal. Ed.*, **13**, 12 (1941).
7. Stuart Cohen and C. C. Ruchhoft. (Presented before Water, Sewage and Sanitation Section of the American Chemical Society, St. Louis, Mo., April 9, 1941).
8. J. M. Holderby and W. L. Lea, *This Journal*, **7**, 36 (1935).
9. W. L. Lea and M. Starr Nichols, *This Journal*, **8**, 435 (1936) and **9**, 34 (1937).
10. E. J. Theriault, P. D. McNamee and C. T. Butterfield, *Public Health Reports*, **46**, 1084 (1931).
11. C. C. Ruchhoft, M. B. Ettinger and W. W. Walker, *Ind. Eng. Chem.*, **32**, 1394 (1940).
12. E. J. Theriault, *Public Health Bulletin No.* **173** (1927).
13. E. B. Phelps, *This Journal*, **2**, 555 (1930).
14. H. W. Streeter, *This Journal*, **7**, 256 (1936).
15. J. K. Hoskins, *This Journal*, **5**, 928 (1933).
16. F. W. Mohlman, G. P. Edwards and Gladys Swope, *Ind. Eng. Chem.*, **20**, 242 (1928).
17. W. Allan Moore. Unpublished data, 1941.
18. R. W. Kehr. Scioto River Report in preparation (1941).

A METHOD FOR COMPUTING THE OXYGEN CURVE IN A POLLUTED STREAM, WITH SPECIAL REFERENCE TO THE OXYGEN CONSUMPTION BY SLUDGE DEPOSITS

By Victor Jansa and Gunnar Åkerlindh

Consulting Engineer, Stockholm, and Engineer of Design, City of Norrköping, Sweden

Different Types of Oxygen Demand

The oxygen demand of municipal sewage or industrial waste induces a corresponding oxygen consumption in the stream into which the sewage or waste is discharged. This oxygen demand can be of three types:

1. The immediate (chemical) oxygen demand, mainly caused by inorganic matter and usually satisfied to 97.5 per cent during 24 hours at a temperature of 20° C.; [1]

2. The biochemical oxygen demand of soluble and suspended organic matter;

3. The biochemical oxygen demand of sludge deposits.

The soluble and suspended matter in sewage causes a momentary pollution of the receiving stream. Consequently a flowing unit volume of the stream becomes polluted at the moment when it passes the point of discharge of the sewage but not farther downstream. The pollution is *carried away* together with the diluting water. Meanwhile it causes an oxygen consumption, creating a variation in the oxygen deficiency, which can be computed according to the method given by Streeter and Phelps.[2]

The pollution caused by the settling solids of the sewage is also momentary, but it acts in another way, because this matter settles rather quickly, thus forming a sludge deposit on the bottom. This sludge forms a stationary pollution, which produces a continual deoxidizing effect on the water above. Consequently, a flowing unit volume of the stream water is exposed to a considerable oxygen consumption from sludge in all stages of decomposition when passing over a sludge deposit—but not thereafter.

As far as we know, no method has been published by which the variation in the oxygen deficiency in a stream can be mathematically computed when consideration is taken also of the oxygen consumption of the bottom sludge. However, such a method is most desirable in many instances. We have, therefore, attacked this problem and arrived at the following conclusion.

Derivation of Formula

The method of computation hereby given is based on Streeter's statement that when a state of equilibrium is reached in a stream "*the amount*

[1] Streeter, "Measures of Natural Oxidation in Polluted Streams. I. The Oxygen Demand Factor." *This Journal*, March, 1935.

[2] Streeter, "Measures of Natural Oxidation in Polluted Streams. II. The Reaeration Factor and Oxygen Balance." *This Journal*, May, 1935.

of B.O.D. added to the deposit each day is substantially equal to the daily amount of B.O.D. oxidized." [3] Consequently, the rate of oxygen consumption at each point of a sludge deposit is equal to the rate of sedimentation, expressed as B.O.D., at the same point. But this also means that regarding a flowing unit volume of the stream, *the oxygen consumption caused by the sludge deposit will proceed in the same way as the sedimentation of settling solids, expressed in B.O.D., from this unit of volume.*

In Fig. 1 the area $OABT$ between the arbitrary curve AB:

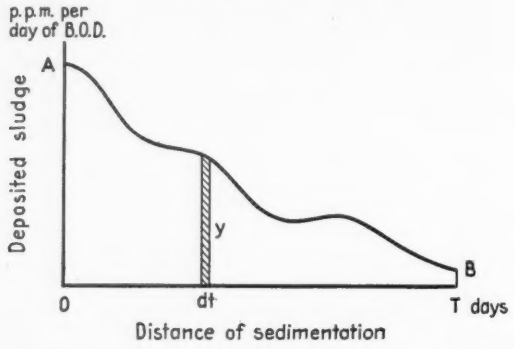


FIG. 1.—Curve of arbitrary shape, $y = f(t)$, indicating the quantity of deposited sludge from a flowing unit volume of the stream in the sedimentation distance OT.

$$y = f(t) \tag{1}$$

and the abscissa axis OT represents the total amount of sludge, expressed as B.O.D., that has settled from a flowing unit volume of water from the point of pollution 0 to a point corresponding to the time of flow T, when practically all settleable sludge has been deposited.

During a short element of time dt the quantity of sludge deposited is:

$$dl_s = y \cdot dt \tag{2}$$

where l_s = quantity of sludge, deposited at the time t.

From Eq. (2) we obtain

$$\frac{dl_s}{dt} = y \tag{3}$$

and

$$\int dl_s = \int y\, dt \qquad \text{or} \qquad l_s = \int y\, dt \tag{4}$$

Equation (4) represents the sedimentation curve obtained when sewage solids are allowed to settle in a beaker (*e.g.*, an Imhoff glass), *i.e.*, it expresses in each instant the total quantity of deposited sludge. The derivative of this curve, which is Eq. (3), will express the rate at which the sedimentation proceeds. However, as mentioned above, the rate of sedimentation, expressed as B.O.D., is substantially equal to the rate of oxygen consumption. Further Eq. (3) and Eq. (1) are identical. Hence

[3] Reference 1.

we reach the conclusion: first that Eq. (1), *i.e.*, the curve AB, at each instant represents *the rate of oxygen consumption of the bottom sludge deposit from a flowing unit volume of the stream;* secondly, that this equation is obtained by deriving the equation of the sedimentation curve of sewage solids settled in a beaker.

The first step in solving the problem is now to find a suitable mathematical expression of the sedimentation curve in quiescent water. In Fig. 2 the full curve follows closely the sedimentation curve given by

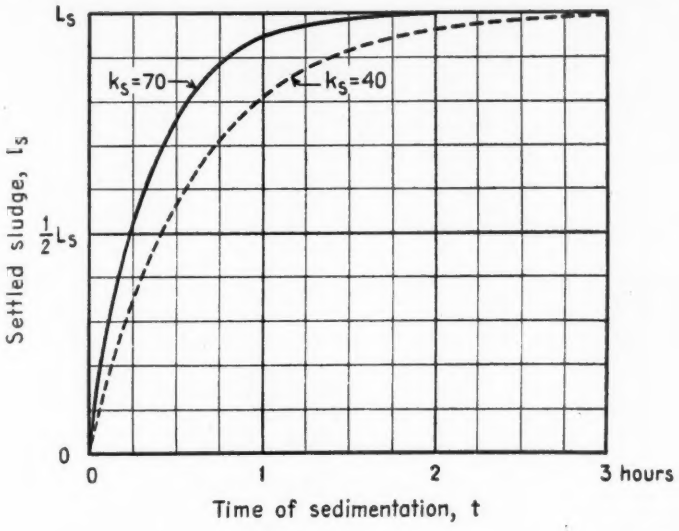


FIG. 2.—Curve $l_s = L_s(1 - e^{-k_s t})$, when $k_s = 70$ and 40 respectively, indicating the total quantity of settled sludge by sedimentation in a beaker.

Imhoff.[4] The full curve in Fig. 2 can mathematically be expressed by the equation:

$$l_s = L_s - ae^{-k_s t}$$

or, because $l_s = 0$ when $t = 0$,

$$l_s = L_s(1 - e^{-k_s t}) \tag{5}$$

where l_s = settled sludge at the time t in p.p.m.;
L_s = total quantity of settleable sludge in p.p.m.;
k_s = specific rate constant of sedimentation (dimension day^{-1});
t = time of sedimentation, in days.

Derivation of Eq. (5) gives:

$$\frac{dl_s}{dt} = k_s L_s e^{-k_s t} \tag{6}$$

which consequently is the *formula of the rate of oxygen consumption, caused by bottom sludge, within a flowing unit volume of the stream,* under the assumption that the sedimentation curve is according to Eq. (5).

[4] Imhoff, *Taschenbuch der Stadtentwässerung.* 8th ed., München and Berlin, 1939.

Eq. (6) has the same shape as the formula presented by Streeter and Phelps for the rate of oxygen consumption caused by soluble and suspended matter. The complete formula for the variation of oxygen saturation deficiency, including the influence of the oxygen consumption of bottom sludge deposits, will, therefore, become an enlargement and a continuation of Streeter and Phelps' formula.

We introduce the following terms:

L_i = immediate oxygen demand in p.p.m.;
L_b = B.O.D. of soluble and suspended matter in p.p.m.;
L_s = B.O.D. of settling solids in p.p.m.;
k_i = specific rate constant of deoxygenation by L_i;
k_b = specific rate constantof deoxygenation by L_b;
k_s = specific rate constant of deoxygenation by L_s;
k_r = specific rate constant of reaeration;
D = oxygen saturation deficiency in p.p.m.;
D_0 = oxygen saturation deficiency at time $t = 0$ in p.p.m.;
t = time, in days.

The rate of deoxygenation, which is the same as the rate of variation of oxygen deficiency caused by L_i, L_b and L_s respectively, according to Streeter and Phelps and the above-mentioned equations, will be

$$\frac{dD_i}{dt} = k_i L_i e^{-k_i t} \tag{7}$$

$$\frac{dD_b}{dt} = k_b L_b e^{-k_b t} \tag{8}$$

and

$$\frac{dD_s}{dt} = k_s L_s e^{-k_s t} \tag{9}$$

The rate of reaeration acting in the opposite direction to these three changes of oxygen depletion, according to Streeter and Phelps, is:

$$\frac{dD_r}{dt} = - k_r D \tag{10}$$

The final variation of oxygen saturation deficiency in each instant is equal to the sum of the influences of the factors given in Eq. (7)–(9). Hence:

$$\frac{dD}{dt} = k_i L_i e^{-k_i t} + k_b L_b e^{-k_b t} + k_s L_s e^{-k_s t} - k_r D \tag{11}$$

This linear differential equation is readily solved by Lagrange's method with variation of the constant. We obtain the final result:

$$D = \frac{k_i L_i}{k_r - k_i}(e^{-k_i t} - e^{-k_r t}) + \frac{k^b L^b}{k_r - k_b}(e^{-k_b t} - e^{-k_r t}) + \frac{k_s L_s}{k_r - k_s}(e^{-k_s t} - e^{-k_r t}) + D_0 e^{-k_r t} \tag{12}$$

Obviously, Eq. (12) constitutes only an enlargement and a continuation of Streeter and Phelps' formula, as the term representing the influence of the actual pollution has been divided into several terms, one for each kind of oxygen demand, each with its own specific deoxygenation rate constant.

Discussion

The full curve in Fig. 2 has $k_s = 70$. As mentioned, the appearance of this curve approaches closely that of the curve given by Imhoff for 2 hours' sedimentation. The Imhoff curve represents sludge volume, it

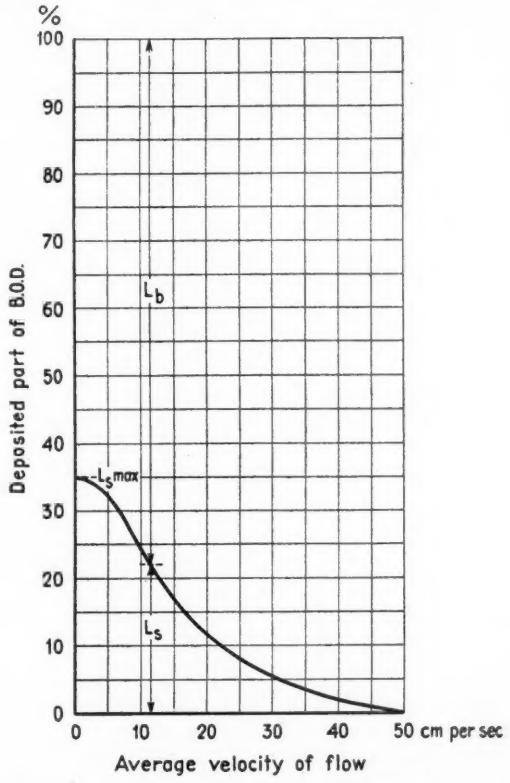


Fig. 3.—Relation between the average velocity of a stream and the quantity of deposited sludge from sewage, expressed as per cent of the total biochemical oxygen demand.

is true, while the curve in Fig. 2 represents biochemical oxygen demand, but these two quantities are likely to be approximately proportional for settled sludge.

However, under natural conditions it may often happen that sedimentation is not concluded after 2 hours, mainly because of the fact that the stream has a greater depth than the beaker in which the measuring has been done. That being the case, a somewhat lower value should be

chosen for the rate constant, *e.g.*, $k_s = 40$. With this value the dotted curve in Fig. 2 is obtained, corresponding to about 3 hours sedimentation time.

It is of great importance that the division of the total oxygen demand into L_i, L_b and L_s should be made correctly. How L_i is determined is already mentioned. After subtraction of L_i from the total oxygen demand, the remainder consists of the biochemical oxygen demand $= L_b + L_s$. The separation of these two quantities, however, cannot be made only by measuring the total B.O.D. and the B.O.D. of sewage settled in a beaker. For in this way only the minimum value of L_b or the *maximum value of* L_s, respectively, is obtained. The actual value of L_s depends on the velocity of flow in the stream, because L_s represents *deposited* sludge and not just settleable solids. If the velocity of flow is sufficient, about 0.50 meters per second or more, no sedimentation at all is likely to take place. Between this limit and zero velocity the value of L_s will vary between 0 and L_s maximum. This variation may be determined approximately. In Fig. 3 this has been done under the assumption, first, that $L_s = 0$ when $v = 0.50$ m/s, secondly, that the sludge-carrying capacity of the stream at low velocity of flow is directly proportional to the velocity, but at a higher velocity of flow directly proportional to the square of the velocity.

Theoretically, L_s is subjected to a slight decrease during the time of sedimentation, because of the existence during this process of an oxygen consumption of the same rate as that of suspended matter. However, this condition is neglected in this method of computation, mainly because the error produced is likely to be less than the degree of accuracy of the analytical data.

Furthermore, it may be pointed out that the method herewith presented may be used, at least for approximate calculations, even when no state of equilibrium is prevailing in the stream. This is, for instance, the case during the early summer, when the decomposition of sludge has come into full swing after having been stopped or at least greatly reduced during the cold season. Such a condition corresponds to a multiple value of L_s.

The method of computation above described has been used by us for calculating oxygen sag curves for the Motala stream through and below the city of Norrköping, Sweden, in such cases where the oxygen consuming effect of bottom sludge deposits had to be considered.

A NOMOGRAPH FOR DISSOLVED OXYGEN SATURATION IN WATER

By W. D. Hatfield

Superintendent, Sanitary District, Decatur, Illinois

The table "Solubility of Oxygen in Fresh and Salt Waters" given on page 153 of the 8th Edition of *Standard Methods of Water Analysis* is incomplete, because (1) many of the streams in the southern area of the United States have summer temperatures between 30 and 50° C., which temperatures are above those given in the table, and (2) corrections for barometric pressures other than those at sea level must be made by equations given below the table. A suggestion that the table should be extended to 50° C. led me to study the possibilities of a nomograph to replace the table which would include pressure, temperature and salinity corrections.

A special slide rule has recently been proposed by A. A. Hirsch, *This Journal*, **12**, 1124–26 (1940), which enables a direct determination of per cent oxygen saturation from analytical results when the temperature, p.p.m., chloride and barometric reading are known. The nomograph proved to be so satisfactory that its publication seems worth while, and subsequent studies and opinions from the field may indicate that it should replace the present table in Standard Methods.

The solubility of oxygen obeys Henry's law, which states that the mole fraction of a gas in solution is proportional to the partial pressure of the gas above the liquid. The partial pressure of oxygen in the atmosphere equals 20.9 per cent of the barometric pressure corrected for the vapor pressure of water at the given temperature and relative humidity, *i.e.*, $pO_2 = 0.209(P - u)$. If this quantity is substituted in the equation representing Henry's law, we obtain:

$$\text{p.p.m. } O_2 = \frac{0.0372(P - u)}{K_t} \qquad (1)$$

in which P is the barometric pressure in mm. Hg, u is the aqueous vapor pressure in mm. Hg, and K_t is the constant for a given temperature as given on page 257, Vol. III, International Critical Tables. If these values of K_t and $t°$ C. are plotted on cross section paper a straight line is obtained between 0° and 35° C. Above 35° C. the constant K_t gradually decreases so that at 50° C. it is 4.44, instead of 4.54 as indicated by a straight line projected through the points from 0° through 35° C. The equation of the straight line is:

$$t° = 18.1\,K_t - 34.7 \qquad \text{or}$$

$$K_t = \frac{t + 34.7}{18.1} \qquad (2)$$

and substituting (2) in (1) we get:

$$\text{p.p.m. } O_2 = \frac{0.67(P - u)}{t + 34.7} \tag{3}$$

In fitting equation (3) to the data in the table in Standard Methods or on page 258, Vol. III, International Critical Tables, a still better fit is obtained by adjusting the constants to:

$$\text{p.p.m. } O_2 = \frac{0.678(P - u)}{t + 35} \tag{4}$$

This equation may be expressed in the logarithmic form

$$\log (\text{p.p.m. } O_2) = \log 0.678(P - u) + \log \left(\frac{1}{t + 35}\right) \tag{5}$$

in which form it is easily placed in a nomograph using single cycle 20-inch log scales for the pressure $(P - u)$ and the temperature $(t + 35)$. The latter scale is inverted because of the fractional form and is numbered in $t°$ C., though, of course, the scale is actually $t + 35$. The "D.O. saturation" scale is a single cycle 10-inch log scale located exactly equidistant between the other two scales and adjusted up or down so that it coincides with any two points located by calculation or from the table in Standard Methods.

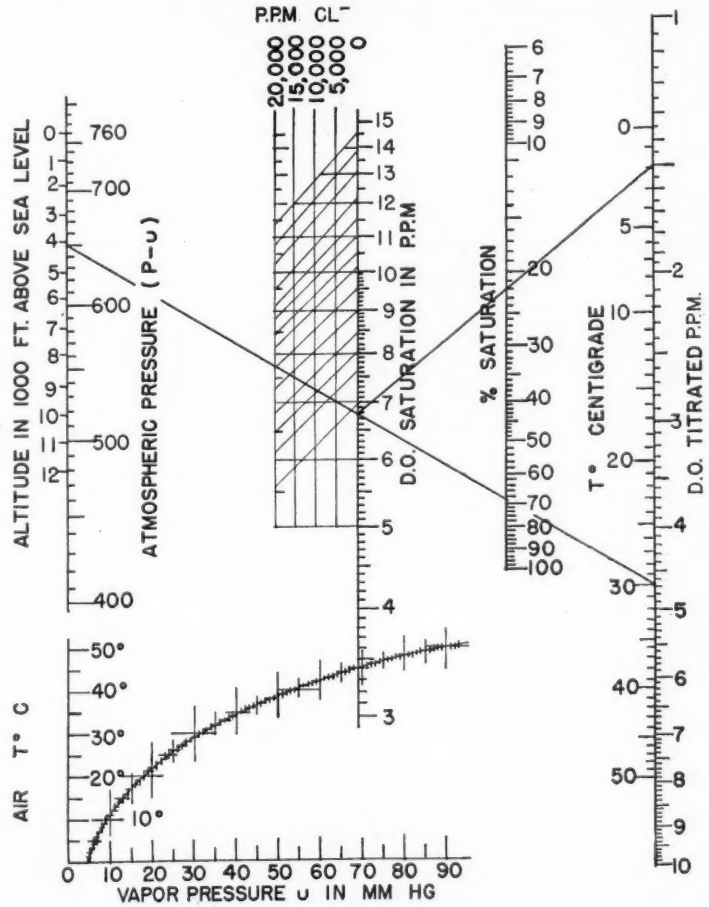
The nomograph now contains three scales from which the dissolved oxygen in p.p.m. may be read for any pressure and temperature likely to be encountered. For convenience the pressure scale is also scaled for altitudes up to 12,000 feet for use when barometric readings are not available.

By placing a straight edge between the barometric pressure corrected for vapor pressure at the given temperature (left scale) and the temperature $t°$ C. (right scale), the dissolved oxygen saturation in p.p.m. may be read directly from the center scale. The correction of the atmospheric pressure by subtracting the aqueous vapor pressure has not been stressed, however, the effect is easily demonstrated by determining the D.O. at 760 mm and 30° C. without corrections (7.9 p.p.m.), and again at 760—32 and 30° C. (7.6 p.p.m.). If the relative humidity was 50 per cent, the D.O. saturation would be about 7.75 p.p.m. This comparison also indicates the rather fictitious accuracy of the second decimal place in the tables previously published. In the lower left hand corner of the nomograph is a curve from which the vapor pressures may be read for temperatures from zero to 50° C.

To the left of the "D.O. saturation" scale is a correction grill for saline waters. Starting with the straight edge reading on the "D.O. saturation" scale follow the correction line down and to the left to a point equivalent to the chloride concentration, then horizontally back to the "D.O. saturation" scale for the corrected reading.

The per cent saturation scale which is a 5 inch, single cycle log scale is placed equidistant between the "D.O. saturation" scale and the $t°$ C. scale.

The latter is scaled on the right side with a 10 inch single cycle inverted log scale from 1 to 10 to represent the dissolved oxygen titrated in the sample under consideration. This scale may be considered a 0.1 to 1.0, 1.0 to 10.0, and 10.0 to 100 with proper adjustment of the decimal place on the "per cent saturation" scale. The "per cent saturation" scale is located by adjusting the 5 in. inverted log scale so that the 100 per cent



Solubility of oxygen in fresh and salt water.

and 10 per cent points are at the intersection of lines drawn between "D.O. saturation" 10, and "D.O. titrated" 1.0 and 10.0.

Let us take for example a titration of fresh stream water of D.O. equal to 1.5 p.p.m., at about 2900 ft. above sea level, with the barometer reading 682 and the stream and air at 30° C. on a rainy day (humidity 100 per cent). Procedure: (1) at 30° C., u = 32 mm. and 682 − 32 = 650; (2) Place straight edge on 650 (pressure scale) and on 30° C. (t° C. scale) and

read 6.8 p.p.m. on the D.O. saturation scale, then swing straight edge to 1.5 p.p.m. on the p.p.m. D.O. titrated scale and read the answer, 22 per cent saturation on the "per cent saturation" scale.

If the above titration were 15.0 p.p.m., instead of 1.5 p.p.m. the procedure would be the same except the answer would be the scale reading $\times$ 10, or 220 per cent supersaturation.

The correction of barometric pressure for the aqueous vapor tension, although a significant figure, may seem to be an unnecessary refinement. The atmospheric pressure may vary on an average 40 to 60 mm. and only above 35° C. is the vapor pressure greater than this variation. For field work it may be more reasonable to use the altitude or the known average barometric reading with an estimated 50 per cent relative humidity for temperatures above 30° C. and no correction for the lower temperatures. However, to obtain the figures given in the tables either in "*Standard Methods of Water Analysis*" or in "International Critical Tables" the 760 mm. atmospheric pressure must be corrected by subtracting the aqueous vapor pressure at the given temperature.

LONG-TIME BIOCHEMICAL OXYGEN DEMANDS AT LOW TEMPERATURES

By Edward W. Moore

Assistant Professor of Sanitary Chemistry, Harvard Graduate School of Engineering, Cambridge, Mass.

The great technical improvements in sanitary engineering accomplished during the last three decades have sometimes caused us to forget that we are still largely dependent on natural forces for the ultimate destruction or stabilization of waste materials. Chief among these natural forces is the assimilation of organic materials by organisms working under aerobic conditions, or in more familiar terms, biochemical oxidation. To understand and control this natural process has been an important objective of sanitary research since the days of Frankland.

To Phelps [1] and Theriault [2] we are indebted for a detailed study of biochemical oxidation in polluted waters, and for a simple and useful mathematical formulation of its course. The validity of their general formulation has been long accepted, but there is still some question as to whether the numerical values of the constants of the formulation as given by Theriault are to be regarded as applicable to all sewages and polluted waters or whether they are to be considered merely as statistical averages from which the values for any individual sewage or polluted water may differ substantially. It is certain that Theriault's values will not necessarily apply to sewages or polluted waters carrying a high proportion of industrial wastes.

Moreover, the course of biochemical oxidation at low temperatures has not been extensively studied. Experiments have been reported by Pleissner at 7° C.,[3] by Greenfield and his coworkers at 2° C.[4,5] and by Theriault at 9° C.,[2] but most work on biochemical oxidation has been confined to relatively high temperatures. The obvious reason for this is that most of the difficulties occasioned by discharge of sewage into water courses occur during periods of warm weather. However, there have been instances in which ice-covered water courses have become anaerobic through biological action, because of inability to renew their oxygen resources. The problem of biochemical oxidation at low temperatures is also of interest with respect to the behavior of trickling filters, activated sludge plants and other biological purification devices under winter conditions.

The experiments reported in this paper represent an attempt to increase our knowledge of biochemical oxidation by studying its course on a number of samples of sewage and polluted waters. These studies have been extended over a long period of time, and over a wide range of temperatures, particularly between 0 and 10° C.

Experimental Procedure

Three series of experiments were performed. In the first two, 2 per cent dilutions of settled domestic sewage in both bicarbonate and phosphate dilution waters (*Standard Methods of Water and Sewage Analysis,* 8th ed., p. 155) were incubated at the following temperatures: first series, 1°, 2.5°, 5.0°, 7.5°, 10° and 18.0° C.; second series, 0.5°, 2.5°, 5.0°, 7.5°, 10.0° and 20.0° C. The incubators were large water baths thermostatically controlled to a precision of $\pm$ 0.2° C. The samples were incubated in individual glass-stoppered bottles, which were withdrawn and titrated in pairs at such intervals as to give a well-spaced B.O.D.-time curve. The sodium azide modification of the Winkler method was used for all dissolved oxygen determinations. In the third series of experiments, undiluted samples from each of two moderately polluted local streams, the Aberjona and Charles rivers, were similarly incubated at temperatures of 0.5, 2.5, 5.0, 7.5, 10.0 and 20.0° C. In all instances the samples were seeded prior to incubation, with seeding material adapted to the particular temperature at which the samples were to be held. This seeding material was prepared by incubating portions of diluted sewage at the respective temperatures for a period of two weeks or more, with occasional addition of small portions of fresh sewage. The incubating material was exposed to the air and shaken frequently to preserve aerobic conditions. Blank determinations were run in parallel with the main series to obtain the demands of seeding material and dilution water, which were deducted from the observed demand of the samples. All dilution water was cooled to the temperature of incubation before use.

Analytical Data

The analyses of the sewages and river samples employed are given in Table I.

Table I.—*Analyses of Sewages and River Samples*

	Results in P.P.M., except pH Value			
	Sewage Series 1	Sewage Series 2	Aberjona River	Charles River
pH value by glass electrode	7.50	7.65	7.30	7.20
Ammonia nitrogen	22.5	11.0	0.038	0.174
Organic nitrogen	28.7	10.8	0.248	0.538
Total solids	319	376	158	1288
Total volatile solids	133	162	43	215
Total mineral solids	186	214	115	1073
Suspended solids	34	118	—	—
Suspended volatile solids	34	100	—	—
Suspended mineral solids	0	18	—	—
Color	—	—	20	50
Alkalinity	—	—	56	22
Nitrite nitrogen	—	—	0.012	0.008
Chloride	—	—	25	635

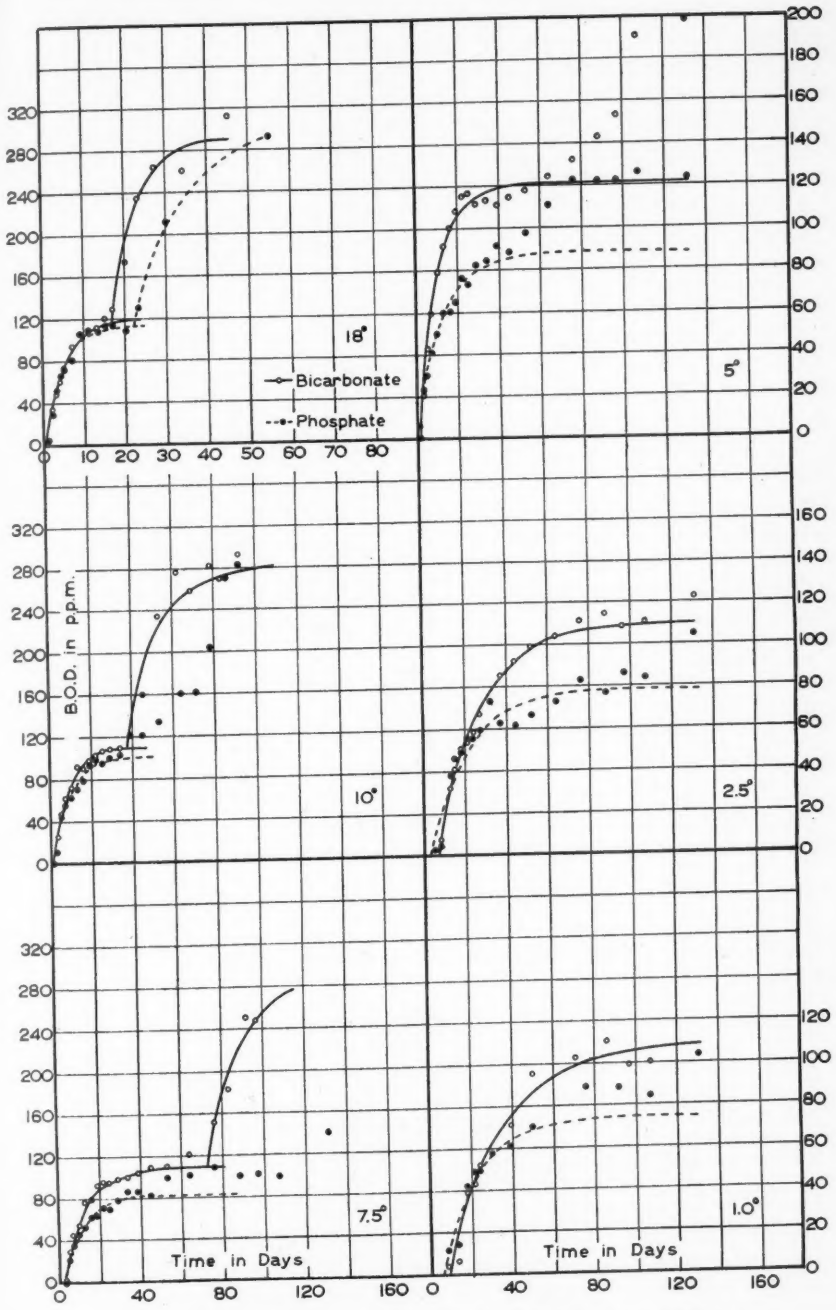


FIG. 1.—Biochemical oxygen demand of diluted sewage. Series 1.

The sewage samples are fairly representative of a settled domestic sewage. The sample used in Series 1 has a higher nitrogen content relative to total solids than that used in Series 2, and this is reflected in the B.O.D. values in that the nitrification demand is higher relative to the carbonaceous demand in Series 1 than in Series 2. Neither of the rivers receives any but small increments of pollution, and much of this is of remote origin, as is evidenced by the low values for ammonia and nitrite nitrogen. The Charles river is subject to some back-flow of sea water, which explains the high chloride content.

Experimental Results

Curves representing the relationship of observed B.O.D. to time for the sewage Series 1 and 2 and for the rivers are shown in Figs. 1, 2 and 3, respectively. In these curves, the circles represent the observed B.O.D.'s (average of two duplicate determinations), and the lines are the theoretical curves of the Phelps-Theriault formulation of the data, as obtained by the "slope method" of Thomas.[6, 7] It will be noted that in most instances the first stage of the B.O.D.-time curve is well represented by this formulation (the unimolecular reaction curve of chemistry). There are, however, some marked deviations from the unimolecular curve in the sewage-phosphate dilution water experiments at the lower temperatures. The significance of these deviations will be subsequently discussed.

The second, or so-called nitrification stage of the biochemical oxygen demand, also appears in most of the experiments, although at the lower temperatures it is long delayed and irregular in development. In some of the studies at 0.5, 1.0 and 2.5° C. it fails to appear as an abrupt rise in the curve, as is usual at high temperatures, and its presence is only indicated by a slow increase in B.O.D., prolonged to the end of the experiment.

Results of Mathematical Analysis

The formulation of the first stage of the B.O.D. curve as developed by Phelps and Theriault is:

$$X_t = L(1 - 10^{-kt})$$

where X_t = Observed B.O.D. at any time, t.
L = Ultimate or total B.O.D.
k = Rate constant of the biochemical oxygen demand.

This can be modified to

$$X_t = L[1 - 10^{-k(t-t')}]$$

to take into account the frequently observed "lag" period, during which the biochemical oxygen demand remains at relatively low values. In this equation t' represents the extent of the lag period. It is evident that any B.O.D. curve which conforms to this equation is completely defined by the values assigned to the constants k, L and t'. The

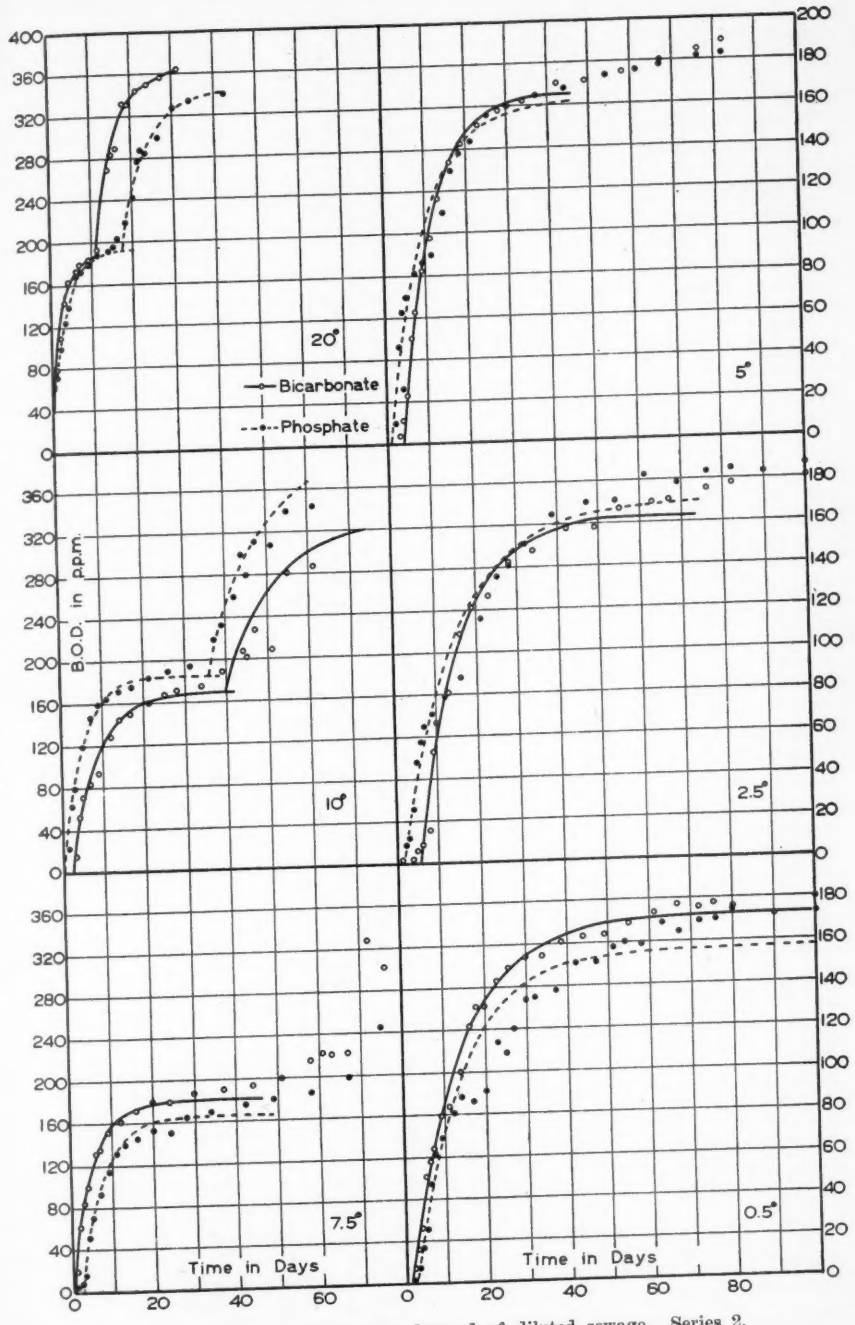


FIG. 2.—Biochemical oxygen demand of diluted sewage. Series 2.

TABLE II.—*Constants of First Stage B.O.D.*

Experiment	Temperature °C.	Dilution Water	Rate Constant k	Ultimate B.O.D. L, P.P.M.	Lag Period, Days
Sewage series 2	20	Bicarbonate	0.182 ±0.022	193.7 ±32.6	−0.2
Sewage series 2	20	Phosphate	0.116 ±0.005	197.4 ±10.6	−0.7
Sewage series 1	18	Bicarbonate	0.105 ±0.017	119.5 ±23.2	0.6
Sewage series 1	18	Phosphate	0.111 ±0.009	114.5 ±11.8	0.8
Sewage series 1	10	Bicarbonate	0.0585±0.0029	110.4 ± 6.8	1.0
Sewage series 1	10	Phosphate	0.0554±0.0072	101.3 ±16.3	1.3
Sewage series 2	10	Bicarbonate	0.0713±0.0097	168.5 ±27.8	2.1
Sewage series 2	10	Phosphate	0.0904±0.0052	185.1 ± 8.3	0.1
Sewage series 1	7.5	Bicarbonate	0.0585±0.0048	98.7 ±10.8	2.7
Sewage series 1	7.5	Phosphate	0.0524±0.0050	81.7 ± 9.8	2.9
Sewage series 2	7.5	Bicarbonate	0.0944±0.0055	181.1 ±13.5	0.3
Sewage series 2	7.5	Phosphate	0.0845±0.0056	165.9 ±13.7	2.4
Sewage series 1	5	Bicarbonate	0.0501±0.0028	121.2 ± 8.5	1.1
Sewage series 1	5	Phosphate	0.0369±0.0045	87.8 ±12.9	0.0
Sewage series 2	5	Bicarbonate	0.0589±0.0033	167.0 ±10.5	3.7
Sewage series 2	5	Phosphate	0.0514±0.0109	162.1 ±42.6	1.0
Sewage series 1	2.5	Bicarbonate	0.0204±0.0018	110.1 ±11.9	6.4
Sewage series 1	2.5	Phosphate	0.0220±0.0043	81.4 ±20.6	3.5
Sewage series 2	2.5	Bicarbonate	0.0436±0.0051	171.4 ±23.1	5.5
Sewage series 2	2.5	Phosphate	0.0331±0.0055	169.4 ±33.6	1.6
Sewage series 1	1	Bicarbonate	0.0159±0.0018	110.1 ±15.4	7.9
Sewage series 1	1	Phosphate	0.0254±0.0076	74.1 ±26.5	5.8
Sewage series 2	0.5	Bicarbonate	0.0358±0.0028	172.5 ±17.4	1.5
Sewage series 2	0.5	Phosphate	0.0367±0.0035	156.9 ±19.1	2.6
Aberjona R.	20	—	0.0256±0.0030	2.64± 0.39	−0.4
Charles R.	20	—	0.0231±0.0021	8.82± 0.95	−0.4
Aberjona R.	10	—	0.0189±0.0094	1.51± 0.80	−0.5
Charles R.	10	—	0.0231±0.0005	3.68± 0.46	−1.0
Aberjona R.	7.5	—	0.0199±0.0100	1.37± 0.90	−1.1
Charles R.	7.5	—	0.0214±0.0043	3.26± 0.76	−2.1
Aberjona R.	5	—	0.0166±0.0039	1.27± 0.34	−8.1
Charles R.	5	—	0.0215±0.0030	2.74± 0.44	−0.1
Aberjona R.	2.5	—	0.0137±0.0036	1.17± 0.34	−1.0
Charles R.	2.5	—	0.0193±0.0068	2.42± 0.96	−1.7
Aberjona R.	0.5	—	0.0118±0.0019	1.48± 0.15	−8.2
Charles R.	0.5	—	0.0155±0.0046	2.38± 0.79	−2.8

equation in its modified form may also be applied to the nitrification stage, and t' then represents the time elapsed before the nitrification stage makes its appearance.

The best evaluation of the constants k and L for a given set of observed data is obtained by some method involving the use of the criterion of least squares. A number of such methods have been developed, including those of Reed and Theriault,[8] Fair,[9] and Thomas.[6] Of the three methods, the latter is the least laborious. The same author [7] has also developed methods for the evaluation of t', and of the probable errors of the computed values of k and L. The methods of Thomas have been used in computing the data presented in Tables II and III, which include the evaluation of constants for all the first-stage B.O.D.'s,

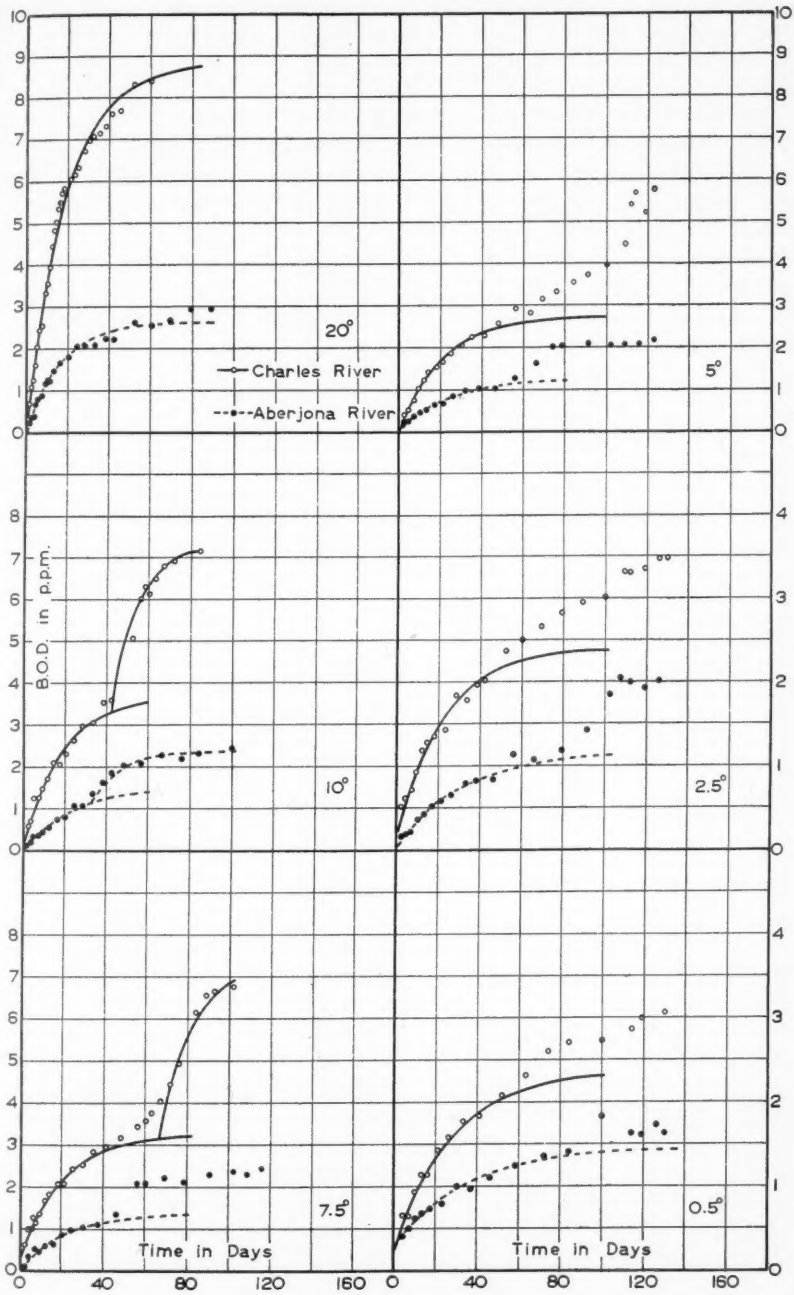


FIG. 3.—Biochemical oxygen demand of polluted river waters.

and for those second-stage B.O.D.'s for which formulation was found to be possible.

Validity of Formulation

With few exceptions, good agreement is obtained for the first stage B.O.D. between the observed B.O.D. values and those computed by the modified unimolecular equation, showing that the equation provides a good representation of the course of oxygen consumption. The exceptions occur mainly at the low temperatures. The second stage of the B.O.D. (nitrification) cannot be represented by this equation at temperatures lower than 7.5° C.; below this temperature the course of nitrification becomes irregular or assumes some form other than that characteristic of the unimolecular equation.

Table III.—*Constants of Second Stage B.O.D.*

Experiment	Temperature ° C.	Dilution Water	Rate Constant k	Ultimate B.O.D. L, P.P.M.	Lag Period, Days
Sewage series 2	20	Bicarbonate	0.0626±0.0069	173.4 ± 23.8	10.0
Sewage series 2	20	Phosphate	0.0634±0.0270	150.4 ± 75.5	16.2
Sewage series 1	18	Bicarbonate	0.0710±0.0200	172.5 ± 59.2	16.8
Sewage series 1*	18	Phosphate	0.042 ± ?	186 ± ?	22.0
Sewage series 1	10	Bicarbonate	0.0323±0.0067	166.6 ± 45.2	37.8
Sewage series 2	10	Bicarbonate	0.0413±0.0217	154.4 ± 90.2	39.5
Sewage series 2	10	Phosphate	0.0336±0.0203	214.9 ±141.8	35.4
Sewage series 1*	7.5	Bicarbonate	0.023 ± ?	193 ± ?	69.9
Sewage series 1	5	Phosphate	0.0259±0.0065	39.4 ± 13.0	47.9
Aberjona R.	10	—	0.0448±0.039	0.85± .96	33.3
Charles R.	10	—	0.0473±0.0059	3.63± .57	42.4
Charles R.	7.5	—	0.0262±0.0064	4.14± 1.23	66.0

* Determined by rough graphical method only, data inadequate for statistical analysis.

In some of the first stage curves for sewage in phosphate dilution water at and below 5° C. there will be noted a tendency toward a break, followed by a secondary rise. Here the data are only approximately represented by the unimolecular reaction, and substantial differences between the observed values and the theoretical curves occur at the point of the break and secondary rise. These differences are reflected in the much higher values of the probable errors of k and L generally obtained at 5° C. and below. The significance of this peculiar behavior, which is not noted at the higher temperatures, can be only a subject for speculation at present. It is not related to the nitrification stage, since it occurs at an earlier time than the well defined nitrification stages observed in the same sewage at higher temperatures. It may possibly mean that the single first stage or carbonaceous process is really a complex of two or more stages which are indistinguishable at the higher temperatures, but become apparent as the velocities are reduced at the lower temperatures.

A more important question is that of the constancy of the value of k. Is it the same for all sewages and polluted waters at a given tem-

perature, even when they are well seeded, adequately buffered, and contain no toxic materials? This has been frequently assumed to be true, and the assumption is undoubtedly good enough for estimating the effects of pollution under practical conditions. However, it is not to be expected that a biological process will show such uniformity of behavior as is observed in chemical reactions. The constancy of k and its dependence on temperature will be treated subsequently, but it may be worth while at this point to call attention to the fact that the k values obtained for the two sewages of Series 1 and 2 may differ to the extent that one value is more than twice the other. For example, the two values for bicarbonate dilution water at 2.5° C. are 0.0204 and 0.0436, respectively. In general, however, the agreement is much better. Attention is also called to the fact that differences exist between the values obtained for the same sewage when incubated in bicarbonate and phosphate dilution waters. The phosphate dilution water generally gives the lower k value, but this is not always so, as shown by the values for Series 2 at 10° C. and Series 1 at 1° C. The differences therefore cannot be specifically ascribed to the effect of the dilution water.

The values of k obtained for the river waters are much lower than those obtained for the sewage dilutions at the same temperature, and will be treated separately.

Effect of Temperature on the Values of the Constants

Using the data available to him Theriault deduced the following relationship between the value of k and the temperature of incubation:

$$k_T = k_{20} \times 1.047^{(T-20)}$$

where k_T = value of k at any temperature T, in °C.
k_{20} = value of k at 20° C. = 0.1.

This relationship gives a straight line when k is plotted on a logarithmic scale and temperature of incubation on an arithmetic scale. A plot of this type for the data of Table II is shown in Fig. 4. It will be noted that the values for the sewage experiments can be approximated by a single straight line down to 5° C., but that some other form of representation, possibly another straight line of greater slope, is required below this temperature.

By the method of least squares, a relationship similar to that of Theriault, but having different numerical coefficients, may be deduced for the two temperature zones. For the higher zone, from 20° C. to 5° C. the equation obtained is:

*(1) $k = 0.135 \times 1.065^{(T-20)}$, where $k_{20} = 0.135$

* Analysis of the results of Sawyer and Rohlich (*This Journal*, 11, 946 (1940)) on the effect of temperature on the base rate of oxidation of activated sludge, yields a value for the constant θ of 1.071, as compared with 1.065 in the above equation. This close agreement between the magnitudes of the temperature effect for two such widely different processes is rather interesting.

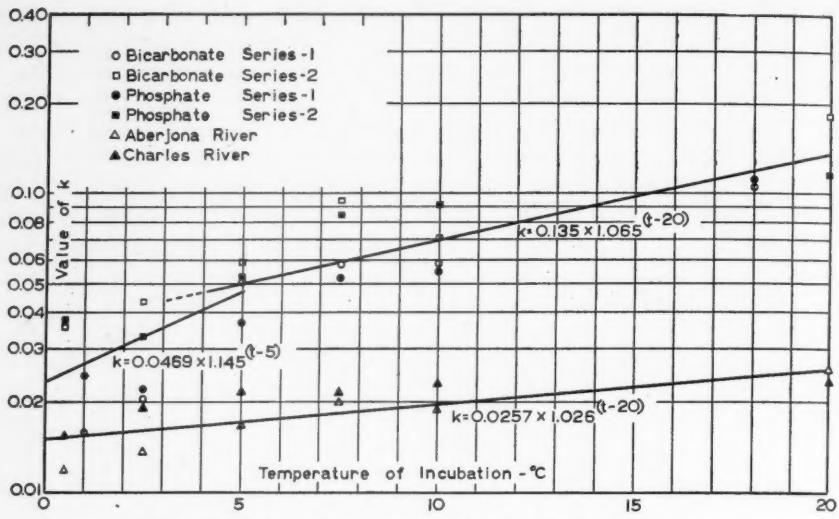


FIG. 4.—Effect of temperature on the velocity constant, k.

For this equation the correlation coefficient, which is a measure of how well the equation represents the data, is

$$r = 0.788 \pm 0.064$$

This indicates a reasonably high degree of correlation.

For the zone from 5° C. to 0.5° C. the equation is:

$$(2) \qquad k = 0.0469 \times 1.145^{(T-5)}, \qquad \text{where} \qquad k_5 = 0.0469$$

The correlation coefficient is

$$r = 0.563 \pm 0.133$$

Here, because of the small amount of data available, and the high degree of variation observed, the correlation is not particularly good, and the equation cannot be regarded as well established. The correlation coefficient is ordinarily required to be at least six times its probable error to be significant, and this condition is not fulfilled. Attention is called to the fact that these equations are for the experiments on sewage only, and do not apply to the river waters.

For the non-mathematical reader the results can best be set forth in Table IV, in which the observed values are compared with those predicted from the various equations.

The observed values in this series of experiments are generally somewhat higher than those predicted by Theriault's equation above 5° C. and somewhat lower below that temperature. It should be noted here that the results of Greenfield and his co-workers [4, 5] on sewage diluted with distilled water yielded k values agreeing very closely with those predicted from Theriault's formula. Their experiments were made at 2°, 14° and 20° C. only.

TABLE IV.—*Comparison of Predicted and Observed Values of k*

Temperature °C.	Observed Values	Average of Observed Values	Predicted from Theriault's Equation	Predicted from	
				Equation 1	Equation 2
20	0.182, 0.116*	0.149	0.100	0.135	—
18	0.105, 0.111	0.108	0.0912	0.119	—
10	0.0585, 0.0554† 0.0713, 0.0904	0.0689	0.0632	0.0720	—
7.5	0.0585, 0.0524 0.0944, 0.0845	0.0724	0.0563	0.0614	—
5.0	0.0501, 0.0369 0.0589, 0.0514	0.0493	0.0502	0.0525	0.0469
2.5	0.0204, 0.0220 0.0436, 0.0331	0.0298	0.0447	—	0.0334
1	0.0159, 0.0254	0.0207	0.0418	—	0.0273
0.5	0.0358, 0.0367	0.0363	0.0408	—	0.0255

* Left-hand value for bicarbonate dilution water, right-hand value for phosphate.

† Upper set of values for Series 1, lower set for Series 2.

Theriault also deduced an equation showing the effect of temperature on the value of L, namely:

$$L_T = L_{20}[1 + 0.02(T - 20)]$$

where

L_T = total ultimate first stage B.O.D. at any temperature T.
L_{20} = total ultimate first stage B.O.D. at 20° C.

Similar equations have been derived by the method of least squares for the data of the sewage Series 1 and 2.

For Series 1 the equation is

$$L_T = L_{20}[1 + 0.0206(T - 20)]$$

and the correlation coefficient, $r = 0.829 \pm 0.070$. In deriving this equation, which agrees substantially with that of Theriault, the values of L for sewage in bicarbonate dilution water at 5°, 2.5° and 1° C. were omitted, since they were obviously out of line with the remainder of the values. This may possibly be due to the fact that a slow nitrification was taking place toward the end of the experiments, and that this tended to give an abnormally high value for L.

For Series 2, the equation found is

$$L_T = L_{20}[1 + 0.0082(T - 20)]$$

with a correlation coefficient, $r = 0.766 \pm 0.081$. All values of L are included. It is evident that the ultimate first-stage B.O.D. of this sewage was less affected by temperature changes than that of the sewage of Series 1, or the sewages studied by Theriault. This becomes more apparent from an inspection of Fig. 5, in which the observed values of L are plotted as a percentage of the derived value of L at 20° C. It is

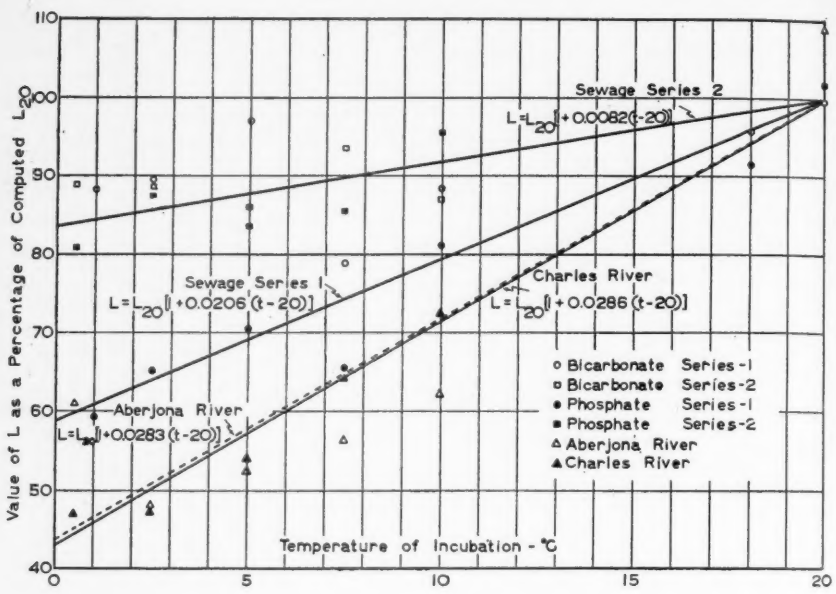


FIG. 5.—Effect of temperature on the ultimate first stage B.O.D., *L*.

also evident from the diagram that the values of *L* for any series show a considerable scatter.

THE LAG PERIOD

Most biochemical oxygen demand curves do not strictly follow the unimolecular reaction curve, but show an initial period of varying length, during which the demand develops more slowly than it does during the later part of the experiment. The net result is that the B.O.D. curve assumes a modified S-shape. The length of this so-called lag period has been shown by Butterfield and Wattie [10] to be directly related to the number of bacteria present in the initial mixture—in other words, to the amount of seeding. Up to a certain limit, according to their work, the greater the number of active bacteria initially present, the smaller is the lag period. It is also possible to have a negative lag period. This condition is indicated by a B.O.D. curve which intersects the *y* axis above 0,0 (as in Fig. 3, 0.5° C.). It is due to the presence of an initial oxygen demand which is exerted much more rapidly than the normal B.O.D.; in fact, in a matter of a few hours.

The equations developed by Thomas for computing the lag period have been applied to the data in hand, and the results are included in Table II. Since the method used for producing the seeding material in the author's experiments does not result in the production of equal numbers of organisms in the seeding liquids for the various temperatures, it is not to be expected that the lag periods at the different temperatures will be strictly comparable. However, there can be noted in

the sewage experiments a tendency for the lag period to increase as the temperature is lowered, and this trend is probably significant. This means, in practice, that there is an additional delay in the development of the B.O.D. at low temperatures, over and above that caused by the relative slowness of the B.O.D. reaction itself.

Time Required to Exert a Given B.O.D.

A simplified, non-mathematical picture of the time-temperature-B.O.D. relationship may be obtained by selecting some arbitrary fraction of the total ultimate B.O.D. observed at the highest temperature studied, and reading from the curves the time required for this B.O.D. value to be reached at all temperatures. Of course the results obtained will vary somewhat with the value selected, so that the picture is only an approximate one. The results of such a survey are given in Table V. The arbitrarily selected B.O.D. values for this table are 80 and 137 p.p.m. for Series 1 and 2, respectively, representing 70 per cent of the average ultimate first-stage B.O.D. at the highest temperature studied in each series.

Table V.—*Time in Days Required to Reach a Given B.O.D. Value*

Temperature °C.	Series 1		Series 2		Average
	Bicarbonate	Phosphate	Bicarbonate	Phosphate	
20	—	—	2.5	4	3.25
18	5.5	6.5	—	—	6.0
10	11	16	13	7	11.8
7.5	16	32	7	12	16.8
5.0	10	31	16.5	17	18.6
2.5	33	76	24	25	39.5
1.0	43	70	—	—	56.5
0.5	—	—	21	37	29.0

The obvious disparity between the average values for 1.0 and 0.5° C. is due to the fact that data for each temperature are confined to one series only. The table shows clearly that as the temperature decreases, the time required for a sewage to exert a given B.O.D. is greatly increased.

The Nitrification Stage

The second or nitrification stage of the B.O.D. curve has always been found more difficult to study than the first stage. This is confirmed by inspection of Table III, in which constants are given for those experiments which exhibited a nitrification stage capable of being formulated. The probable errors of the constants are much higher on a percentage basis than those found for the first stage. For this reason, only the values of the constants are given, and no attempt has been made to formulate their relationship to the temperature of incuba-

tion. The value of k for the nitrification stage in the sewage experiments appears to be about 0.06 for 20° C., 0.03 to 0.04 for 10° C., and 0.02 to 0.03 for 7.5 and 5.0° C. These results are not in agreement with the studies of Streeter,[11] who derived a value of 0.031 from experiments of the Sanitary District of Chicago on Illinois River water at 20° C. In experiments reported by Thomas,[7] the value of k for nitrification at 23° was found to be 0.062 for sewage in a well seeded dilution, and 0.023 for the same sewage at the same dilution when unseeded. The value for the seeded dilution is of approximately the same magnitude as the values obtained in the author's experiments.

At low temperatures the nitrification stage appears to be inhibited, and may only appear as a continued slow rise of the B.O.D. curve beyond the point at which the first stage B.O.D. has been satisfied. Under these conditions it is difficult to determine where the nitrification stage actually begins, and part of this slow rise may be inadvertently included in the first stage. The value of L obtained will then be out of line with that obtained for other experiments, and this may explain the results of the experiments on sewage in bicarbonate dilution water at 5.0, 2.5 and 1.0° C. in Series 1.

TABLE VI.—*Time in Days Required for the Establishment of Nitrification*

Temperature °C.	Series 1		Series 2		Average
	Bicarbonate	Phosphate	Bicarbonate	Phosphate	
20	—	—	10.0	16.2	13.1
18	16.8	22.0	—	—	19.4
10	37.8	38*	39.5	35.4	37.7
7.5	69.9	53*	51*	42*	54.0
5.0	64*	47.9	42*	44*	49.5
2.5	131*	97*	63*	61*	88
1.0	—	76*			—
0.5			100*	63*	82

* Estimated from diagrams.

The lag period for the nitrification stage is of especial interest, since it is an index of the time at which a substantial nitrification demand begins to be exerted, and thus has a bearing on practical stream pollution studies. Where formulation of the nitrification stage is not possible, the lag period cannot be computed exactly, but it is sometimes possible to estimate from the curves the time at which a substantial nitrification demand sets in. In Table VI, values are presented for the lag period or for this estimated time for the sewage experiments, in order to give a picture of the effect of temperature on the incidence of nitrification.

It is evident that below 10° C., the nitrification stage is so long delayed that it need not be considered to any great extent in practical stream pollution studies. It is also observed that nitrification is generally better developed in the more alkaline bicarbonate dilution water than in the phosphate water, a fact previously noted by other workers.

River Water Studies

While the results of the sewage studies are more or less in agreement with the work of other investigators, the results of the studies on water from the Charles and Aberjona Rivers are anomalous. The values of k obtained for the first stage B.O.D., at 20° C. are only about 25 per cent of those normally expected, and remain low at all temperatures, although the proportional decrease in the k value at the lower temperatures is not as great as that for the sewage studies. The values of L, the total first stage B.O.D., are low, as befits streams subject only to moderate pollution. In general, the Charles River tends to yield higher values of k than those obtained for the Aberjona river, although this is not true for the 20° C. results.

The reason for the unexpectedly low k values can only be surmised. It is not lack of proper seeding, since the same seeding technique was employed as in the sewage experiments, and furthermore, both river waters had a temperature of 9° C. at the time of collection, and must have contained organisms adapted to low temperatures. The rivers in question are subjected to successive small increments of pollution, rather than one large dose, and the B.O.D. observed in these experiments may be that exerted by residual organic materials of resistant character. On the other hand, since some industrial pollution is received by both streams, the low values of k may result from the presence of inhibiting substances in the river waters. Or it might be considered that the rivers are already in the nitrification stage, for which the values of k are known to be lower than the corresponding first-stage values. This latter theory, however, leaves one with the problem of explaining the second stage observed in some of the experiments.

Another anomaly of this series of experiments is the fact that the lag periods observed are all negative. This signifies an immediate oxygen demand of some sort. It cannot be the type of immediate demand observed in sewage that has become anaerobic, for both waters were well supplied with dissolved oxygen at the time of collection. It must be due either to an immediate oxygen demand of an entirely different type, or to some interaction between the river water and the seeding material. Another possibility is that there may be a systematic error in the blank demand, which was obtained by incubating in standard dilution water, a dilution of the seeding material equal to that used in the main experiments. This blank demand, deducted from the observed total demand of river water and seeding material, might not represent the true blank of the seeding material as exerted in the river water mixtures. However, the total blank demand was in no case greater than one or two tenths of a p.p.m., and it is difficult to conceive of a gross error from this source.

When analyzed by the same method as that used for the sewage experiments, the relationship of the value of k to the temperature of incubation for both rivers taken together is found to be best represented by the equation:

$$k_T = 0.0257 \times 1.026^{(T-20)}$$

for which the correlation coefficient, $r = 0.704 \pm 0.098$. The effect of temperature on the value of k is thus not as great as that observed in the sewage series. This analysis covers the entire range from 20° to 0.5° C., and the relation of the observed values to the straight line given by the equation is shown in Fig. 4.

Analysis of the effect of temperature on the value of L gives for the Aberjona River the equation

$$L_T = L_{20}[1 + 0.0283(T - 20)]$$

and for the Charles River the equation

$$L_T = L_{20}[1 + 0.0286(T - 20)]$$

The correlation coefficients are, respectively, $r = 0.738 \pm 0.126$ and $r = 0.784 \pm 0.116$. In this analysis, the value for L for the Charles River at 20° C. is omitted, since it is out of line with the remaining values. It apparently includes both of the stages, which are obviously separated in the other experiments. The observed results and the straight lines given by the equations are shown in Fig. 5.

Like the sewage experiments the experiments on river waters show a second stage, which in a few instances can be formulated. The values of the constants thus obtained are given in Table III. The k values appear similar in magnitude to those obtained for the nitrification stage in the sewage experiments. On this basis, it is possible that this second stage may represent a true nitrification stage, although supporting evidence on the nitrogen changes during incubation is not available. Like the nitrification stage in the sewage experiments, this second stage is delayed at the lower temperatures. If the time required for its appearance is estimated as in the case of the sewage experiments, the results given in Table VII are obtained:

TABLE VII.—*Time in Days Required for the Establishment of Second Stage*

Temperature, ° C.	20	10	7.5	5.0	2.5	0.5
Aberjona R.	—	33	56*	66*	79*	100*
Charles R.	—	42	66	56*	51*	63*

* Estimated from diagrams.

These times are comparable in magnitude with those obtained for the sewage experiments.

SUMMARY AND CONCLUSIONS

A series of studies has been made on the biochemical oxygen demand of diluted sewage and river waters at low temperatures. It is concluded from these studies that:

1. The first stage of the biochemical oxygen demand is well represented by the modified unimolecular relationship of Phelps and Theriault, when account is taken of the lag period. Exceptions to this

rule occur in some experiments at and below 5° C., where there appears to be a secondary rise in the oxygen demand.

2. The value of k, the rate "constant" for the first stage B.O.D. at a given temperature should be considered as a statistical average rather than as a true constant. In some polluted streams its value may be much lower than the generally accepted value, and in some sewages much higher, at least when they are incubated in standard dilution waters.

3. The effect of temperature on the values of k and L for the first stage are adequately represented by the equations developed by Theriault. However, the numerical coefficients of these equations found in the studies here reported are somewhat different from those given by Theriault. The differences are particularly notable in the values of k for experiments at or below 5° C., which are considerably lower than those predicted by Theriault's equation.

4. The second or nitrification stage of the biochemical oxygen demand is greatly retarded at low temperatures, and its development becomes uncertain and irregular. At the higher temperatures it can be formulated by the unimolecular relationship, with a lag period. Some values of the constant k for this formulation are given.

References

1. E. B. Phelps, U. S. Geol. Survey, *Water Supply Paper No.* **229**, 74 (1909).
2. E. J. Theriault, *Public Health Bulletin* **173** (1927).
3. M. Pleissner, *Arb. Kais. Gesund.*, **34**, 320 (1910).
4. R. E. Greenfield and A. L. Elder, *Ind. Eng. Chem.*, **18**, 291 (1926).
5. R. E. Greenfield, A. L. Elder, and R. E. McMurray, *Ind. Eng. Chem.*, **18**, 1276 (1926).
6. H. A. Thomas, Jr., *This Journal*, **9**, 425 (1937).
7. H. A. Thomas, Jr., *This Journal*, **12**, 504 (1940).
8. L. J. Reed and E. J. Theriault, *J. Phys. Chem.*, **35**, 673, 950 (1931).
9. G. M. Fair, *This Journal*, **8**, 430 (1936).
10. C. T. Butterfield and E. Wattie, *This Journal*, **10**, 816 (1938).
11. H. W. Streeter, *This Journal*, **7**, 274 (1935).

Editor's Note: Part of this paper was presented before a meeting of the American Chemical Society in Boston in September, 1939. Dr. Howe has kindly released this portion of the paper.

THE OPERATOR'S CORNER

Conducted by W. H. WISELY, Executive Secretary*
Federation of Sewage Works Associations
Box 18 · · Urbana, Illinois

AN OPEN LETTER TO O. P. RATOR

May 1, 1941

Mr. O. P. Rator,
c/o Sewage Treatment Works,
Clean Creek, U. S. A.
Dear Mr. Rator:

An earnest effort is being made to make this Journal of greatest possible usefulness to sewage works operators in plants of all sizes. We are hopeful that The Operator's Corner can become as useful and beneficial to you as is the technical portion of the Journal to engineers and chemists engaged in the more scientific branches of our profession.

Attainment of the above aim is possible only if practical and interesting operation information is made available to us and this can come from but one source—men such as you who are actively working in the operation field.

While formal articles and papers will always be welcome, it is realized fully that it is often difficult for an operator to obtain the time and facilities for preparing them. Consequently, we shall be just as glad to have your contribution in the form of a letter or as crude notes and will be happy to undertake the task of working it into shape for publication. This may enable you to pass on some worthwhile experience or advice without necessitating preparation of an article.

We shall occasionally impose on your good nature by writing you for specific material. However, in the course of your work, you will constantly encounter items which would be of value and interest to other operators. At all times, we shall appreciate material of the following types:

1. Methods of solving operation problems of every kind.
2. Descriptions, with photographs or sketches, of any useful "gadgets" you may have developed.
3. Photographs "telling a story" of some unusual or otherwise interesting operation situation.
4. Copies of annual operation reports.
5. News items of general interest. If flavored with a little humor—so much the better.
6. Prepared articles or papers.

* Also *Engineer-Manager,* Urbana and Champaign Sanitary District.

With your assistance, Mr. Rator, THE OPERATOR'S CORNER will have a fair chance of success. Since this is *your* department, we invite your criticisms, ideas and suggestions as well as contributions. May we enjoy your cooperation?

Cordially yours,

W. H. WISELY,
Executive Secretary,
Federation of Sewage Works Associations

ELECTRICAL EQUIPMENT MAINTENANCE

This summary of practice in maintaining electrical equipment in sewage works has been developed from material furnished by operators representing nearly all sections of the nation. The Corner gratefully acknowledges the highly practical contributions of the following:

C. George Andersen, Superintendent, Rockville Centre, New York.
C. O. Baetz, Superintendent, Appleton, Wisconsin.
Ray H. Corr, Superintendent, Water and Sewers, Woodstock, Illinois.
Perry Cram, Superintendent, Sewage Treatment, Colfax, Washington.
William D. Denise, Superintendent, Greece, New York.
R. E. Doonan, Superintendent, Municipal Utilities, Waverly, Iowa.
Gerald Hilborn, Operator, Spring City, Pennsylvania.
C. T. Mudgett, Superintendent, Muskegon, Michigan.
W. P. Petrie, Superintendent, Norwalk, Connecticut.
C. R. Price, Superintendent, Rapid City, South Dakota.
J. E. Rehler, Superintendent, Olean, New York.
Edward J. Rhoads, Superintendent, Lancaster, Pennsylvania.
E. E. Smith, General Superintendent, Lima, Ohio.
J. L. Todd, Superintendent Municipal Utilities, Kewanee, Illinois.

FREQUENCY AND METHODS OF INSPECTION

Some form of daily inspection of motors and switchboard equipment, with a thorough inspection at least once each week, appears to be universal practice. At Lima, Ohio, and Norwalk, Connecticut, the respective semi-annual and quarterly investigations by insurance inspectors have been found advantageous in locating sources of possible difficulty.

The "feel" test (applying the back of the hand to the operating motor) has been found adequate at Appleton, Wisconsin, to reveal any tendency toward heating or grounding of equipment and is a regular daily routine at all motors. The daily test for grounds at Greece, New York, has resulted in locating several of these in the past, although none were considered serious.

The megohmmeter, or "megger," which is an instrument measuring insulating resistance of motor windings and supply lines, is used at Olean and Rockville Centre, New York, for periodically checking all electrical equipment. This service is afforded by the local power companies annually at Rockville Centre and every four months at Olean. At the latter plant, a graph of the "megger" readings is maintained and if an appreciable resistance drop is shown, a detailed inspection for the cause is made. It is considered that no motor should show winding insulation resistance of less than one megohm. The city's electrical inspector at Rapid City, South Dakota, cooperates with Superintendent C. R. Price by making periodic instrument tests and observations for grounds, short-circuits and insulation breakdown.

The practice of Superintendent Denise at Greece, New York, of maintaining a card filing system for recording detailed inspections, lubrication and repairs to equipment appears highly commendable.

Motor Maintenance

The importance of proper lubrication of motor bearings is generally manifested by the frequent attention afforded. The appearance (whether dark or gritty) and oil level at all oil-lubricated bearings is checked at least weekly. Grease-packed bearings are usually given routine attention less frequently, this task being allocated to one man at Muskegon, Michigan, and Norwalk, Connecticut, to avoid excessive greasing which is considered harmful. An excess of grease causes bearings to run hot.

Complete replacement of oil or grease in motor bearings is provided from 1 to 4 times yearly, with semi-annual attention being most common. Andersen (Rockville Centre) considers quarterly replacement of oil in bearings well justified because considerable dirt is drawn into the lubricant along the shaft and the cost of the small amount of oil required is minor. Petrie (Norwalk) washes the old grease from ball bearings with carbon tetrachloride before repacking with fresh lubricant. In general, the recommendations of the motor manufacturer are carefully followed in the choice of lubricant for each purpose.

Advantage is usually taken of the opportunity to thoroughly inspect the mechanical condition of bearings at the times of lubricant replacement. A spare stock of replacement bearings is considered advisable at Kewanee, Illinois, to prevent shortage of equipment while parts are on order.

Routine removal of dust, dirt and other accumulations from motor windings by blowing out with compressed air from 1 to 4 times monthly, is common practice. Excessive air pressure (above 80 pounds) and use of air containing excessive moisture is to be avoided. High pressures may damage the insulation and expose the wiring and moist air may dampen the insulation causing a "short." Rhoads (Lancaster) employes a small portable blower for this purpose.

When "megger" measurements indicate low resistance in the winding insulation, excessive dampness or break-down of the insulation is indicated. A small, bowl-type electric heater has been successfully used to dry out motors by Rehler (Olean). If the insulation has been softened by moisture, oil or grease, it may be cleaned and washed with carbon tetrachloride, then painted with an insulating varnish or paint such as glyptal lacquer. Unless skilled electricians are employed in the plant, motors requiring such special work as the above are sent to the shop for servicing.

Maintenance of an equalized air gap between the rotor and stator of the motor is important from the standpoint of efficiency and to prevent damage in case the two parts come into contact. Badly worn bearings may cause an unbalanced air gap and this item must also be checked when reassembling a motor which has been torn down.

Petrie (Norwalk) and Andersen (Rockville Centre) report that all motors, after 8 and 10 years service, respectively, were inspected by competent advisers and were overhauled by cleaning, baking and reinsulating. Andersen points out that this practice is well justified since the cost, on motors originally costing $300 to $500, was only $4.00 per motor per year.

Petrie (Norwalk) points out the desirability of operating all motors a short time during each day, especially where there is dampness. The heat and ventilation induced in the operating motor will dry it out and the short period of operation will keep the lubricant in gears and other machine parts. This practice should be kept in mind when any part of the plant is temporarily removed from service.

Maintenance of Switchboards

Continuous inspection and cleanliness appear to be the most important fundamentals of successful switchboard maintenance.

Daily checks for loose terminal connections (especially where subject to vibration) and for dirty contacts, with prompt attention where found to be necessary, is universally practiced. Darkening of contacts or excessive noise and arcing during operation indicates the contacts to be worn or in faulty adjustment. Dressing of slightly roughened contacts with a fine file or sandpaper is approved but there should be no hesitancy in replacing these with new ones as they become worn.

At motor starters, aside from the contactor work described above, the only other routine care involved is the occasional oiling of contactor shaft bearings, replacement of worn mechanical parts and making sure that the arcing shields are properly placed at all times. Hilborn (Spring City) has found that a coating of vaseline on the laminated iron core of the starter thermal relay affords lubrication and protection from rust.

Overload relays, circuit breakers and fuses have the important function of protecting the board and motors from overloads, excessive voltage variations and other circumstances which might cause damage. To

be effective, thermal overload relays and circuit breakers must be accurately adjusted and fuses must be of the proper capacity. Capacities and adjustment of such protective equipment is best established initially by a competent electrician. Corr (Woodstock) cites an instance when the power supply "single-phased" during the night, causing damage to three motors because the fuses were not of proper capacity.

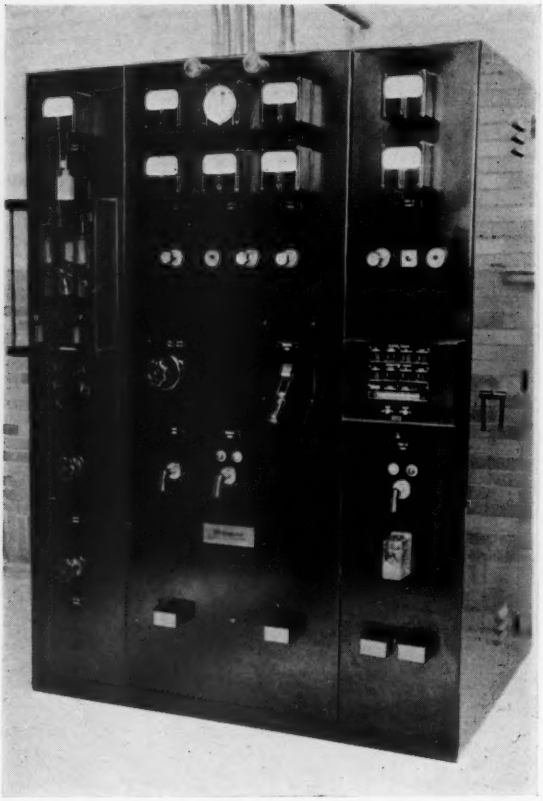


FIG. 1.—Cubicle switchboard for gas-engine driven generator at Peoria, Illinois.

To protect electric equipment from lightning and high-voltage "surges," installation of lightning arresters is often worthwhile. Todd (Kewanee) reports that several solenoid coils on the power company side of the automatic double-throw switch ahead of the gas-engine driven generator were lost until lightning arresters were placed in the power line just outside the building. This protection might have prevented lightning damage to the switchboards at Waverly, Iowa, and Spring City, Pennsylvania, and repeated damage from switchboard "flash-overs" (probably due to "surges") at Springfield, Illinois.

A good stock of common replacement parts is indispensable to proper switchboard maintenance. Rehler (Olean) supplements the

usual stock of contactor points, springs and fuses with spare magnetic contactor coils and a time limit relay for emergency use.

The synchronous timers controlling operation of mechanical aerator motors at Kewanee, Illinois, originally equipped with high-speed motors, gave considerable trouble until the manufacturer furnished low-speed motors in replacement. Due to bearing difficulties in the high-speed units, the timers lagged and disrupted the aerator operation schedule.

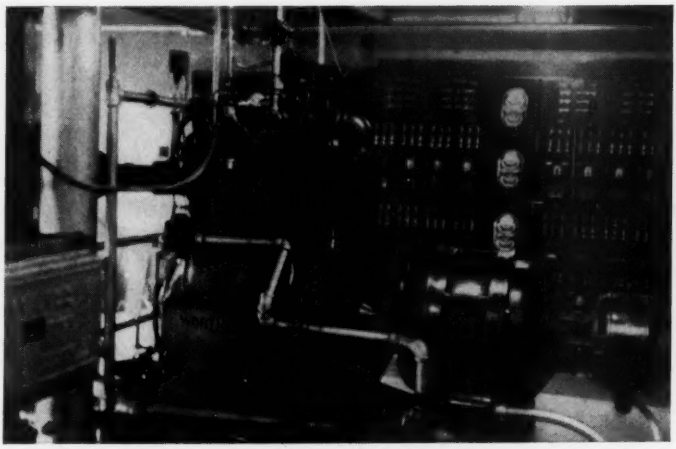


FIG. 2.—Gas-engine driven generator and switchboard at Kewanee, Illinois.

PROTECTION FROM MOISTURE AND CORROSION

Few sewage treatment works are so fortunate as to have all electrical equipment located in surroundings which are free from dampness and this cause is undoubtedly responsible for more repair and replacement work than any other. So many problems of this kind have been observed in the experience of the Corner that the following has been inspired, and is included here in case the reading matter thus far has been too "dry":

Is there a plant where moisture's bad
That never in itself has had
A lot of "shorts" and grounds and so—
Because of too much H_2O?

If cold and warm air meet and mix
Condensate puts you in a fix,
But you can stop it—just don't let
The atmosphere get too damp wet!

Elimination of the source of moisture, special arrangements for ventilation and provision of heating facilities to reduce condensation are the most common methods of affording a proper environment for electrical equipment. In locations such that dampness cannot be corrected, moisture-proof motors are usually provided and the control

panels placed in a favorable location. Mudgett (Muskegon), however, has found that even moisture-proof equipment was not entirely satisfactory in certain underground lift stations and that relocation of control equipment and provision of better ventilation has been required.

A serious condensation problem in an underground pumping station at Spring City, Pennsylvania, resulted in serious damage in only two months time due to the control panel being located at an elevation at which condensation was prevalent. Relocating the panel at a higher elevation at which condensation was prevalent. Relocating the panel at a higher elevation and sloping all conduit to low points at which drip holes were drilled has effected a satisfactory solution. Andersen (Rockville Centre) corrected a chronic power feed problem where the conduit was subjected to moisture by replacing the original wiring with new wires having heavier lead insulation.

At Olean, New York, forced ventilation successfully corrected a condensation condition in an underground pumping station which had caused a mold to develop in the insulation of the motor winding. Extra provision for ventilation at two large stations and an annual October to June heating schedule at all but one of the five stations has adequately controlled dampness at Lima, Ohio.

The presence of hydrogen sulfide, the most common corrosive gas about sewage works, is first manifested by darkening of all exposed copper followed by progressive destruction of the metal. Since moisture is essential to the reaction which occurs, the methods of dampness control described above should minimize damage by such corrosion. Elimination of the point of entry of the gases is logical, as at Colfax, Washington, where modern wet well floats replaced old devices having openings.

A wide variety of insulating paints, varnishes and lacquers are available through electrical supply companies for use in protecting switchboards, exposed coils, etc., where severe dampness or corrosive conditions exist. In painting, care must be taken to avoid spread of paint between contacts and connections as this will reduce the current carrying capacity at such points.

Elimination of Electrical Hazards

Accident hazards to operating personnel and visitors have been largely removed at modern, enclosed switchboards and control panels, but no installation can be considered entirely fool-proof. In many early plants employing old-style equipment, much protection remains to be furnished by the operator. Proper insulation and grounding of equipment is part of the original installation but an occasional item may be overlooked during construction and must be corrected later.

At Lancaster, Pennsylvania, the top and back of the switchboards are screened by wire grills and only the electrician is permitted to enter the enclosure. Red tags reading "Danger, Men Working on This Unit" are placed on switch handles controlling circuits under repair. Grill

enclosures are used at all switchboards at Lima, Ohio, also. All motors outside the control building at Kewanee, Illinois, are equipped with weather-proof disconnect switches mounted thereon enabling the repair man to work on them without fear of having the main control switch inadvertently closed.

Andersen (Rockville Centre) and Rehler (Olean) emphasize the importance of thoroughly dry floors and the desirability of rubber matting about switchboards. A supply of rubber gloves is kept on hand at Rockville Centre for use during maintenance work on electrical equipment.

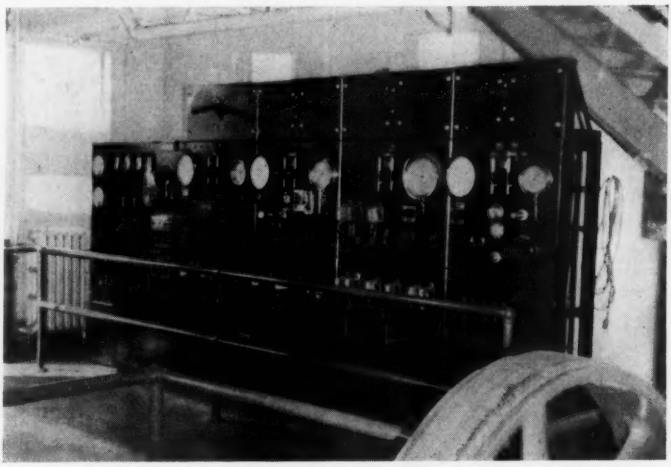


FIG. 3.—Open switchboard at Urbana-Champaign, Illinois, installed in 1924. Note dead-front disconnect switches at top—added in 1940.

At many plants, such as that at Appleton, Wisconsin, explosion-proof motors and electrical appurtenances are used, particularly where the equipment is located in rooms into which sewer or digester gases may escape.

SUMMARY

In general, the following cardinal rules of electrical equipment maintenance appear to be observed by practical plant operators:

1. Make frequent inspections and make repairs and adjustments as soon as they are found necessary.
2. Keep motors and appurtenances clean at all times.
3. Do everything possible to maintain a dry environment, free of corrosive gases, at all electrical equipment.
4. Unless electrical specialists are part of the plant personnel, do not hesitate to obtain competent advice and service when special problems arise. When in doubt, call the electrician.
5. Take no chances with respect to accident hazards. Accidents which are "impossible" sometimes occur.

The Corner has recently embellished its library with a new book, *Troubles of Electrical Equipment,* by H. E. Stafford (McGraw-Hill), which is highly recommended to sewage works operators. The volume is most practical, containing concise tabulations giving the symptoms, troubles, causes and remedies of all types of electrical equipment difficulties. The following general maintenance schedule, which closely follows the practice of the sewage works operators who have collaborated in this article, is taken from the book:

Daily:

1. All bearings examined to note if oil rings are working, temperatures noted, and oiled if necessary.
2. Ground connections and motor leads examined.
3. Motor windings felt for heating.
4. End play noted.
5. Control equipment examined.
6. Oil tanks of all compensators especially examined for presence of moisture, where equipment is located in damp places.

Weekly:

1. Examine oil in bearings to ascertain if it is gritty or darker in color than usual.
2. Test air gap between rotor and stator of motors where there is excessive belt tension.
3. Blow out windings of motors situated in dusty locations.
4. Examine starting equipment for burned contacts where motor is started and stopped frequently.

Monthly:

1. Renew oil in all high-speed bearings in damp and dirty locations.
2. Overhaul compensators, magnetic switches, and controllers.
3. Inspect and clean oil-circuit breakers and knife switches.

Quarterly:

1. Drain all bearings, wash with kerosene, flush with lubricating oil, and refill all motor bearings where motors are operating in damp and dirty locations.
2. Fill grease bearings with new grease.
3. Windings of motors subjected to corrosive or other elements cleaned, baked, and varnished if necessary.
4. All motors blown out.

Yearly:

1. Check and renew, if necessary, all high-speed bearings.
2. Overhaul motors subjected to severe operating conditions.
3. Change the oil in all starters in damp places or wherever subjected to corrosive elements.
4. Switch and fuse contacts renewed if badly pitted.

Note: The Corner will welcome your comments concerning material of this kind. We feel that it represents practical plant operation experience and should be worthwhile.

A similar compilation of practice in controlling scum accumulation in sludge digestion tanks is planned for the July issue. Any of you having an interesting problem or solution to such a problem are cordially invited to contribute.

INTERESTING EXTRACTS FROM OPERATION REPORTS

GREEN BAY, WISCONSIN (1939–40)—GEORGE MARTIN, *Superintendent*

Two-Stage Digestion Operation Schedule.—The solids which were removed by the four clarifiers were placed in four digesters that were maintained at a temperature of 70–80° F. These solids which amounted to 3,544,512 pounds of dry material contained 2,307,388 pounds of volatile matter which upon decomposition produced 19,645,640 cubic feet of 65 per cent methane gas averaging 8.5 cubic feet of gas per pound of volatile matter added to the digesters. The gas so produced was used for heating the treatment plant and for fuel in two sludge gas burning engines.

When originally built these digesters were operated as primary or one-stage tanks but because they were overloaded they produced a supernatant liquor that carried large quantities of solids back to the clarifiers. Because of this it was thought advisable to change the operation so that the digesters would be operated as two-stage tanks. To do this it became necessary to convert the two floating covered digesters into primaries and the stationary covered ones into secondary digesters. In operating two-stage, supernatant liquor or sludge was pumped out of the primaries into the secondaries with the supernatant liquor of the two secondaries overflowing into the clarifiers. The raw sewage sludge was then pumped to the two primary digesters. Digested sludge was drawn from the secondaries directly to the sludge beds. The digesters were then resealed by pumping liquor either from the side or the bottom of the primaries. It so happens that the sludge at the bottom of the primaries is almost always at a lower volatile value than the secondaries. Therefore sludge from the bottom of the primaries is usually drawn directly to the sludge beds. As the primaries have floating covers, they do not need resealing and until the covers reach their highest level it is not necessary to remove supernatant liquor. This gives the secondary digesters a good chance to operate at low loadings and consequently produce a supernatant effluent which is low in suspended solids.

In maintaining the digesters at a temperature from 70–85° F. it was necessary to circulate a total of 20,308,100 gallons of heating water ranging in temperature from 100–144° F. through all four digesters each of which contain 640 feet of 1¼ in. continuous heating coil.

Gas Utilization for Power.—In 1937 when the capacity of the treatment plant was doubled there was included in the new project a power house wherein were installed two Worthington type BG, 514 r.p.m. sewage sludge gas engines, one a three cylinder, ninety horse power and the other a four cylinder, one hundred and twenty horse power, each direct connected to an 80 and 105 K.V.A. 4000 volt induction generator which produced the power needed to operate the pumps and the various other electrical equipment in the sewage treatment plant. In addition to the above mentioned units there was included a fifty foot spherical gas storage tank and two gas compressors.

When these engines were first proposed there was some question as to whether or not the investment would be a wise one but as all gas engine installations which had been investigated indicated that the units paid for themselves in a few years, the two units were included. In order to actually determine whether or not the investment was sound a book set-up was made on a utility basis showing all costs involved in the generation of electricity by the utilization of sewage gas. Because the Green Bay Metropolitan Sewerage District's sewage treatment plant was a P.W.A. project under which 45 per cent of the cost was borne by the Federal Government it was thought advisable to make two set-ups, one to include the total cost ignoring the fact that the Federal Government had donated a part of it, and the other based on the actual cost or money expended by the District. The first of these shows a total investment of $73,062.86, with the structures which included the power house and the footings for the storage tank amounting to $33,985.32, the gas engines and generators $16,865.08, and the gas holder $20,674.50, and the gas compressors $1,537.96. The other account covering the District's 55 per cent shows a total cost of $41,107.70. In computing the profits from these units the various items listed under capital investment were depreciated in accordance with their classification. For instance, the structures were depreciated at 2 per cent, the gas engines at 6.6 per cent, the gas holder at 2.5 per cent, and the gas compressors at 10 per cent per year.

During the first ten months that these engines operated they produced a net return of $2,828.42 based on the actual cost to the District or $1,111.51 on the 100 per cent basis. At the end of the second year of operation the 55 per cent cost showed a net profit of $9,347.08 against $5,772.72 for the 100 per cent cost and now at the end of the third year of operation these engines show a total net profit of $15,924.42 on a 55 per cent basis against $10,519.65 for the 100 per cent cost. In order that a clearer picture of last year's operating costs might be shown the following summary tabulation is presented:

	100% Cost		55% Cost	
Power Used (2¢ per K.W.H.)		$12,877.30		$12,877.30
Int. on Cap. Invest. @ 2½%	$1,712.60		$ 963.71	
Dep. on Structures and Equip.	2,495.35		1,413.83	
Ins. on Power House and Gas Holder	54.96		54.96	
Rep. and Main. Gas Eng. and Gen.	633.88		633.88	
Rep. and Main. Gas Comp.	11.32		11.32	
Lub. Oil—3 cyl. eng.—217½ gals.	122.65		122.65	
Lub. Oil—4 cyl. eng.—219¾ gals.	123.95		123.95	
Lub. Oil—compressors—57¾ gals.	32.58		32.58	
Operating Labor	237.33		237.33	
Rep. and Main. Labor	559.04		559.04	
Comp. on Labor @ $1.69	13.46		13.46	
Actual 39–40 Operating Cost	$5,997.12		$4,166.71	
Total Power Purchased 39–40	2,133.25		2,133.25	
Annual Operating Cost		8,130.37		6,299.96
Net Profit—April 1, 1939–March 31, 1940		$ 4,746.93		$ 6,577.34
Net Profit—April 1, 1938–March 31, 1939		4,661.21		6,518.66
Net Profit—June 1, 1937–March 31, 1938		1,111.51		2,828.42
Total Net Profit to Date		$10,519.65		$15,924.42

From this tabulation you will note that no attempt has been made to favor the engines. In fact everything possible has been charged against them in order not to misrepresent their earnings. Thus, there has been charged every minute of time that has been put in on these engines by District employees and here it might be said that it probably isn't fair to do this as all of these employees are monthly men and whether the District had gas engines or not, these men would have been employed. Taking all things into consideration about the only things that were not charged were the superintendent's and office clerk's time and rent for the land occupied by the power house and gas holder. Also, it should be pointed out that no credit is given the engines for heating which is derived from their cooling system. Here all the cooling water from these engines passes through the plant heating system and sufficient heat is given off to keep the District's four digesters up to a temperature above 75° F. However, the reason why no credit is given these engines for the heat derived from them is that if there had been no gas engines, the gas would have been burned directly in boilers and thereby used to heat the plant.

Stream Studies Protect Sewerage District.—While collecting data on the East River it was noted that above the city of Green Bay the dissolved oxygen of the river water was zero and the hydrogen sulfide content was 0.2 p.p.m. whereas at the same time there was dissolved oxygen and no hydrogen sulfide in the river water below the city limits. This indicated that there was pollution entering the river above the city of Green Bay. A survey of three cheese factories located near the river disclosed that all of them were discharging their wastes into the river and samples collected at their outlets had a maximum B.O.D.

of 2180 p.p.m. This condition was reported to the State Board of Health and we hope that in the near future changes will be made to eliminate this industrial waste.

Odor Control.—Odors in the plant caused by hydrogen sulfide always increased during the winter months. This undoubtedly was due to the decrease in flow which resulted in a greater detention period in the sewers and clarifiers, thereby causing the sewage to become septic and produce hydrogen sulfide. To control the hydrogen sulfide the inlet sewer was continuously pumped clean. This prevented the accumulation of septic solids and consequently reduced the hydrogen sulfide in the raw sewage. Over the weekend when flows were normally lower than during the rest of the week a bypass station at the upper end of the District was partially opened so that about a million gallons of river water per day would run into the sewer. In addition to increasing the flow and thereby decreasing the detention period it also helped flush the main intercepting sewer once a week and materially reduced the hydrogen sulfide and the resulting odors.

DeKalb, Illinois (1940)—D. E. Henn, *Superintendent*

Moisture and Electrical Equipment.—The mechanically cleaned bar screen operated efficiently throughout the year with one exception. About 2 cu. ft. of screenings were removed daily and were disposed of by burying. The building, screen channel and screen were kept in a sanitary condition by cleaning them at least once each week by flushing with water and removing the screenings daily. The only repair necessary was to the motor which burned out on the 11th of December after almost eleven years of service under very damp conditions. This motor was re-wound by the Chicago Electric Co. of Chicago and triple dipped and triple baked to waterproof the windings. The motor was put back in service on the 23rd of December and should give many more years of service. The screen was raked by hand while the motor was being repaired. Due to the excessive moisture conditions within the building the electric switchboard is in a very bad condition and will have to be rebuilt in the very near future. It is evident now that this switchboard should have been rebuilt in the summer of 1940 as recommended by the superintendent in the last annual report.

Automatic Sludge Pumping.—This unit, which pumps sludge from the primary settling tank to the digester, operated without trouble other than cleaning the valves occasionally and installing one set of new diaphragms.

New diaphragms were put in the pump on February 12th to replace those that had been installed in May, 1937. The diaphragms replaced had been in service 33 months, the longest any had ever lasted in this pump.

On the 27th of January the time clock which operates the pump automatically 3 times each day, and which had been in the repair shop since November, 1939, was replaced and the pumping schedule which had been

maintained prior to November, 1939 was re-established. The schedule runs the pump automatically for 15 minutes each at 1:00 P.M., 10:00 P.M. and 3:00 A.M., and manually at 7:00 A.M. and 4:00 P.M. for periods of from 15 to 30 minutes each, depending on the sewage flow and solids in the primary tank. The benefits of this schedule have been demonstrated at our plant for several years, as reported in previous reports.

Sludge Digestion.—Several times during the year considerable difficulty was experienced in operating this very important unit.

On January 8th the drain from the overflow clogged and it was necessary to dig 10 feet into the digester terrace to free it. A rock which evidently had been accidentally dropped into the drain had clogged the pipe. The packing of the sludge valve at the bottom of the digester was loose, and as this valve was adjacent to the overflow drain it was decided to uncover this valve at the same time and to build a manhole around it so that not only could the packing gland be tightened, but the valve could be reached whenever necessary in the future without uncovering it. This valve is 20 feet below the top of the digester, and an extended stem working in a valve box had been used to operate it. The uncovering of this valve and the construction of a manhole 20 feet deep was quite an undertaking for the regular plant personnel, but it was finally completed and backfilled and the terraces replaced without an accident of any kind. The extended stem is still used to operate the valve and works in the manhole through the hole in the manhole cover.

Sludge was drawn from the digester early in May, but soon after the secondary was put into operation, with the filters unloading, the digester filled with very thin sludge and the overflow was heavy. With quantities of secondary sludge to handle and the overflow return to the primary heavy, the sludge pump had to be run for excessive periods in an effort to keep the primary tank clean. This excessive pumping under the above conditions upset the digester to the point where it foamed several days in June. By drawing sludge from the digester to the storage tanks and pumping raw sludge from the primary direct to the storage tanks, the digester settled down somewhat the latter part of June. However, this procedure, coupled with the late cold spring and wet weather, produced a rather serious sludge problem the last week in June. The primary tank was septic due to a heavy sludge blanket in it, the digester was full of thin sludge, both storage tanks were full of sludge and water, and no drying beds were clean into which sludge could be drawn. This situation cleared itself up with the hot, dry weather of July, when many beds were cleaned. Some trouble in keeping the digester in condition was experienced all during July and August, and it wasn't until September that the unit settled down to normal operation, to give no further trouble during the balance of the year.

Emergency Heater.—The weed burner purchased in August, 1939, gave very good service, burning weeds along road- and walk-ways and

on the digester terraces. It was also used to burn out a patch of Canadian thistles in the field east of the digester. A new use was found for this burner early in the winter when it was used in place of gas to heat water in the hot water system of the office in order to furnish heat for the building while sludge was being withdrawn from the digester and no digester gas was available.

Congratulations!—In April the Superintendent received a "Certificate of Competency—Class I—Sewage Works Operator." This certificate was issued by the Sanitary Water Board and is signed by Dr. A. C. Baxter, director and chairman. Application for these certificates is voluntary on the part of the operator and is not required by law.

BUFFALO, NEW YORK (1939–40)—C. R. VELZY, *Supt.;* G. E. SYMONS, *Chief Chemist*

Pumping.—The Main Pumping Station has operated throughout the year without interruption and without any major expenditure for maintenance and repair.

A study has been started in cooperation with the Sewer Department to determine the relation between pumping rates, sewage levels at the pumping station, and the elevations of the sewage level in the various intercepting chambers at times of storm. The object of this study is to establish a pumping schedule for storm flows which will result in a minimum of overflow, consistent with reasonable pumping cost.

Screening and Grit Removal.—Operation of screen and grit removal mechanisms was normal throughout the year. During the months of August, September, and October, 1939, the storm flows brought large quantities of leaves which were caught on the screens. This resulted in some shearing of pins on the mechanical rakes. When the load of leaves was excessively heavy they were removed from the belts rather than trying to grind them and return them to sewage, where they would cause difficulty in handling sludge farther along in the treatment process. Having been removed from the belt they were deposited in compost piles for use in landscape work.

The renewal of wearing shoes on grit elevator buckets and replacement of wearing rails in the grit sumps were accomplished during the year. The original wearing rails were made from 20 pound railroad rails set in the concrete. These were replaced with removable channels faced with a wearing strip of spring steel. Observations indicate a better life with this arrangement and the renewal of wearing parts will be considerably simplified.

In January, 1940, an experimental chute was installed on grit machine No. 1 to investigate the possibility of washing some of the organic matter from the grit as it is collected. Experience with this device indicates that it may be of some value. Further work is contemplated.

Replacement of worn parts on that portion of the raking mechanism submerged in sewage was started during the year. Some modifications are being made to facilitate prompt and economical replacement.

Sedimentation.—Settling tank operation proceeded normally throughout the year without interruption except for the routine inspection and maintenance work. The removal of suspended solids continued to be normal for flows up to the designed capacity.

Further attention was given to the inlet baffling arrangements for the purpose of obtaining better removal of solids at the higher flows. In this connection, the lower half of the inlet baffle plates was removed from one of the tanks and the entire plate from one of the other tanks. Observations thus far are not conclusive, but the indications are that improvements can be made. The work on this problem is being continued.

Alterations in the piping and arrangements for handling scum after it is skimmed from the settling tanks were made. Considerable improvement was accomplished in the process of scum handling. The pumping of scum is still a problem because of the large amount of sticks and other coarse material which it contains. This problem is still being studied and further improvements are contemplated.

During the year, excessively high pressures were encountered on the sludge discharge line. It was found that this was due to the congealing of grease on the inside of this line. The line was successfully cleaned with steam. This is apparently a somewhat unusual occurrence. Extensive inquiry has not disclosed a similar experience in any other plant.

Maintenance work on the settling tanks has included the leveling of the mechanism in No. 4 tank, cleaning of two of the sludge suction lines and checking of settlement of the floor in tanks No. 3 and No. 4, where foundation conditions were bad. These floors were designed to take settlement without damage to the tanks. Inspection showed no damage to the tanks, although floor slabs showed appreciable settlement in some locations. A careful record of the amount of settlement was made for tank No. 3, but it was considered unnecessary to make floor repairs at the present time. The tanks were, therefore, returned to service and have been operating normally.

Sludge Tanks.—The operation of the sludge tanks has been characterized by gas production considerably above that anticipated. In order to distribute this large quantity of gas to better advantage, a large capacity gas booster was transferred from the incinerator building to the sludge control building. The use of this larger capacity booster makes it possible to distribute larger quantities of gas at higher pressures and thus give better service to the boilers and incinerators.

Sludge tanks frequently accumulate a scum composed of grease and other floating materials. During the year a scum layer of this nature accumulated on the top of the sludge tanks to a depth of 6 to 8 ft. During the winter, this layer of scum became quite dense, analyzing as high as 30 per cent solids. Because of its depth and density, it was troublesome for a few months. Late in the spring when the tanks became more active, this layer of scum became soft. With the flexible piping arrangements in the sludge control building, it is possible to

draw scum from the top of the tanks for burning along with the sludge, and it appears that the scum can be controlled by this procedure.

During a part of the first half of the year, sludge accumulated in the tanks to the extent that the supernatant withdrawn and returned to the settling tanks was heavier than normal. This condition was probably aggravated somewhat by the accumulation of large quantities of scum or floating material. The situation was overcome by burning sludge at increased rates until the excess sludge in the tanks had been reduced.

Sludge Disposal.—During the first three months of the year, representatives of the contractor were present, making adjustments in the

SUMMARY OF OPERATION DATA (JULY 1, 1939 TO JUNE 30, 1940)

Item	1939–40 Average
Sewage Flow	135 m.g.d.
Sewage Flow	225 g.c.d.
Suspended Solids	
Raw Sewage	165 p.p.m.
Per Cent Removal—Overall	31.5 %
Per Cent Removal—By Clarifiers	26.5 %
Settleable Solids—Per Cent Removal by Clarifiers	85.4 %
5-Day B.O.D.	
Raw Sewage	137 p.p.m.
Per Cent Removal	23.1 %
Chlorination	
Chlorine Demand—Raw Sewage	5.4 p.p.m.
Chlorine Demand—Supernatant	239 p.p.m.
Chlorine Demand—Combined	5.9 p.p.m.
Chlorine Dosage	5,580 lb. per day
Coliform Bacteria	
Raw Sewage	72,500 per ml.
Effluent	1,299 per ml.
Per Cent Kill	98.2 %
Grit Removal	3.80 cu. ft. per m.g.
Moisture Content	46.4 %
Volatile Matter Content	37.2 %
Raw Sludge (Wet)	343,000 g.p.d.
Solids Content	6.62%
Dry Solids	190,000 lb. per day
Volatile Content	56.4 %
pH	6.6
Sludge Digestion	
Digestion Temperature	85.6° F.
Gas Production	0.79 c.f. per cap.
Gas Fuel Value	633 B.T.U. per c.f.
Supernatant Liquor	282,000 g.p.d.
Solids Content	3.91%
Volatile Content	47.0 %
pH	7.3
Digested Sludge	59,000 g.p.d.
Solids Content	10.13%
Dry Solids	52,000 lb. per day
Volatile Content	42.9 %
Specific Gravity	1.04

Item	1939–40 Average
Sludge Dewatering	
Quantity Wet Cake	79 tons per day
Solids Content	37.8 %
Volatile Content	38.1 %
Lime Dosage	11.62% (by wt. D.S.)
Ferric Chloride Dosage	3.10% (by wt. D.S.)
Fuel Value Sludge Cake	3,790 B.T.U. per lb.
Incineration	
Time Operated	769 hrs. per mon.
Wet Cake	2,396 tons per mon.
Dry Cake	1,808,000 lb. per mon.
Grit	152,000 lb. per mon.
Dry Solids Burned	1,960,000 lb. per mon.
Gas Used	2,544,000 c.f. per mon.
Ash Quantity (Dry)	29,300 lb. per day
Volatile Content	3.62%
Boiler Operation	
Oil	328 gal. per day
Gas	297,000 c.f. per day
Steam	173,000 lb. per day

incineration equipment following the acceptance tests which were run in May, 1939. This work was finished in September.

Following the test period, sewage gas was used exclusively as an auxiliary fuel for the incinerators. This resulted in smoother operation than had been obtained with the use of oil. It is particularly well adapted to the operation of the automatic control which maintains furnace temperature.

The burning of the grit was started in September and the testing and adjustments to the grit feeding equipment extended over a period of several months. By January all grit was being burned. While some difficulty was first encountered in burning grit in an amount equal to a quarter of the sludge, it was soon found that grit and sludge could be burned in almost any proportion with sludge. For several periods, therefore, grit has been burned in various proportions with sludge, and for several periods grit has been burned alone. The process and the feeding equipment have proved particularly satisfactory. It is worthy of note that this is the first definite application of burning as a method of grit disposal.

In connection with the problem of abrasion on incinerating and drying equipment, some alterations were worked out in cooperation with the contractor on the construction of the flash dryer. These alterations involved the use of bars with replaceable sleeves in the cage mill of the dryer. One unit was equipped with these bars and sleeves and has been in use for a short period. Experience thus far indicates that this is an improvement. The demonstration is still underway and further investigation and study is to be made during the coming year.

Normal furnace operation included the use of two furnaces at a time. During the month of March and April, however, operation was reduced to part time operation of one furnace. This was due to the

lower removal of solids from the sewage during these months of high sewage flows.

Miscellaneous Items.—The yards and grounds became an operating department this year. Our gardener was employed starting in July, 1939, and took over the care of the grounds following the landscaping contract. Trees, shrubs, and grass withstood the winter well, and during the summer of 1940 the grounds have been quite attractive.

The final tests on the heating boilers were made during August and October of 1939. These tests, made under the supervision of Greeley and Hansen, showed the boilers to meet the specifications. The total steam load on the boilers was somewhat lower this year than during the previous year. With this reduced steam load and an appreciably higher quantity of gas available, the fuel oil consumed was reduced from 343,896 gallons in the previous year, to 119,937 gallons during the past year. One boiler was capable of carrying the entire load at all times during the year.

During October, 1939, the new Hamburg Pumping Station was completed. In the early part of October, the contractor placed the station in operation and turned it over to the Sewer Authority on October 24. Steam was carried on the old station to the end of October at which time the old station was abandoned. The usable equipment in the old station was salvaged and the building was turned back to the city.

Beginning in the latter part of March, 1940, the Buffalo Broadcasting Company broadcast three programs over the radio from the Sewage Treatment Works under their program entitled "Behind the Scenes."

Miscellaneous development work carried on during the year, included further study of the sludge cake feeder installed on the filters, trial runs on different types of filter cloth, installation of a heater to supply hot water for lime slaking, studies on the problems of abrasion, and adjustments to feeding equipment to handle sludge conditioning chemicals.

NOTES FROM WESTERN NEW YORK

Taken from the Minutes of the Fourth Quarterly Meeting of the Western New York Section of the New York State Sewage Works Association, held at Kenmore, New York, on December, 14, 1940. Reported by Section Secretary G. E. Symons.

Public Relations.—The technical portion of the program of the December meeting included three papers. In the first on "Promoting Public Relations in the Sewage Treatment Industry," Chairman Al. Martin suggested that through the medium of section meetings, state meetings and cooperation of the public relations committee, we are in a position to intelligently execute a program.

In discussing the relation of sewage treatment plant management to programs of promoting public relations, Mr. Martin suggested that

the first first step is to acquaint the management with the plans of the program through the public relations committee and meetings of these executives and representatives of the Board of Health.

Mr. Martin's second suggestion was that the management should consult with employees and discuss working hours and conditions, education policies and wages. Further, the management should make available to the employees, data and facts on the financial relationship of the management to the plant, and should consider and discuss suggestions made by employees.

A third step in promoting public relations, should be taken by management and employee together. The public should receive full information concerning the operation of the plant through the medium of newspapers. Invitations to visit the plant should be issued to the general public and to engineering societies, Kiwanis, Lions, Rotary Clubs, Chambers of Commerce, Scout Troops, church groups and other organizations. Groups should be courteously conducted through the plant and information presented to them should be of such a nature that it is informative, not confusing. Charts and flow diagrams are frequently helpful in this regard. Visitors should be made to feel that it is their plant and they are free to visit it any time.

Mr. Martin further suggested that to acquaint the public with the problems of sewage treatment, the Sewage Works Association should create a speaker's bureau along geographical lines with the thought that speakers would then be available to present the subject to interested groups.

The discussion of this paper was led by Mr. C. R. Velzy, Chairman of the Public Relations Committee of the N. Y. S. S. W. A. Mr. Velzy raised the point of what must be done first in order to accomplish the intention of the program that Mr. Martin had outlined, and suggested that if the management were not interested in carrying on their part of the program, the operators must start from the bottom and carry it on themselves.

Considerable interest was shown in the subject and several questions were asked and suggestions made. What should the small plant do? Could it make use of the local paper? The answer was that regardless of the size of the city, the attempt should be made to "get the newspaper on your side," by making available to the paper information that is of general interest concerning the operation of the plant. Likewise, regardless of the size of the plant, organizations should be definitely invited to visit the plant, and, if possible, dates set for their visits.

Another suggestion, particularly for larger cities, was to interest the "Better Voter Club" or "Better Citizen Club" who make nonpartisan studies of local government. An effort should be made to have these clubs "make your program their program." Another suggestion was that operators might put notations on their monthly reports to the State Department asking that the Department bring certain features of the operation of the plant to the attention of the management.

In conclusion of the long discussion, it was suggested that operators having problems on public relations should make the effort to contact the Public Relations Committee.

Pumping Problems.—The second paper on the technical program was entitled, "Pumping Installations and Pumping Problems," by Newell Nussbaumer. See *this Journal,* **13**, 318–324 (March, 1941).

Bearing Maintenance and Lubrication.—The third paper on the technical program was a discussion of bearing maintenance and lubrication by Mr. Burt Brown, President of the Acme Bearing Company. Mr. Brown described the making of a ball bearing, showing examples of the product as it appeared in various stages of the process, and stated that all ball bearings were made out of the same steel, using the S. A. E. specification to produce an item which was definitely a precision product, with very close tolerances. Ball bearings are not even handled by hand after completion in order to prevent any effect of moisture from the hands on the ball.

Saying that there were 15,000 types of ball bearings with each type having a particular job, Mr. Brown said that with proper application, ball bearings will outlast the machine in which they operate. Some of these types of bearings, which were exhibited, included precision bearings, lubriseal, thrust, radial, self-aligning and multiple roller.

In commenting on the use of ball or roller bearing, Mr. Brown mentioned that it was true that "nothing rolls like a ball, but that it takes a roller to carry the load" and he told of the rather destructive advertising campaign which arose from these facts. Although these statements remain true, the two fields of industry are no longer in competition over the applications involved, but are developing both for their special uses.

Regarding the care of bearings, Mr. Brown pointed out that at least seventy per cent of the bearing failure is due to too much lubrication and showed a new type fitting which allows only the proper amount of lubrication by grease. In the care and cleaning of bearings, Mr. Brown cautioned that gasoline and carbon tetrachloride should not be used to clean the ball bearings because when these solvents evaporate there is a film left on the ball. In preference, kerosene should be used and the balls soaked for about two hours and then blown absolutely dry by a current of clean dry air. One other caution in the care of ball bearings is to make sure that containers of grease are never left open to the air. The unused grease in the pail should be covered at all times.

In answer to a question as to whether it was safe for an operator to take a manufacturer's recommendation for grease on different types of equipment, Mr. Brown stated that in general it probably is, but that one could not make an absolute statement in this regard. He said that there was no one grease that was the best for all uses, but that when in doubt vaseline was probably the safest to use.

DAY BY DAY WITH O. P. RATOR

May 3—Marked the end of a long, hard winter by cleaning up the furnace room. Remarkable how a little aluminum paint will brighten up a spot like this!

May 5—Began setting out plants in flower garden, realizing that the summer's visitors will be more likely to remember this spot than any other part of the plant, so that work done here is amply justified. Also began spading earth around shrubbery according to previously prepared schedule. (With 47 acres of park to maintain, the schedule is essential for systematic work.)

May 6—Picnic season (in our park) initiated by a group of nurses from Burnham Hospital. Very easy to find someone to show them about the plant!

May 10—Sounded Imhoff tanks. Looks like we're " over the hump " now that good weather for sludge drying has arrived. The frozen vents and scum-covered settling channels of last January and February are gone but not forgotten—we've got to figure out something to minimize that trouble next winter!

May 14—Professor Babbitt's senior class of sanitary engineers out this afternoon to inspect the plant. One of them asked, " What are the duties of a sewage works superintendent? " The meeting adjourned about 2 hours and 20,000 words later.

May 21—Monkey-glanded our venerable, 16-year old sump pump by a thorough overhauling from suction screen to motor. This is about the last time such a job will be worthwhile, for the pump has had a long, hard life. Page the " Wise-Retirement " principle!

May 23—High school biology class visited plant, the fourth group of school children to come out this month. Let 'em come—the young folks who visit us now are going to be appreciative and interested (we hope) tax-payers in a few years!

May 29—The more we see of this violent hosing of Imhoff tank gas vents, the less we like it. Remember the fable in which the Sun wins a wager from the North Wind by beaming down on the weary traveller, causing him to remove his overcoat, after the North Wind had failed to forcibly blow the coat from the man's back? We did, and got an idea from it, about which we'll tell more later.

May 31—" Short " in wiring of clarifier mechanism, seemingly an aftermath of the flood of a year ago when water inundated some of the conduits. The next time we have a flood, the Voice of Experience will remind us to blow out and dry out all electric conduits, as soon as the water recedes.

June 1—Right at the peak of the trickling filter unloading period. Compilation of the May laboratory data reveals that 35,400 pounds of dry solids came from the filter during the month. When this load is added to the normal raw solids load to be digested (about 80,000 pounds per month), the reason for common digestion tank upsets during the unloading season is obvious.

June 5—Our first official Board Meeting! Made out fairly well except for nearly forgetting to present bills (and payroll) for payment..

June 6—For wood exposed to excessive moisture in damp locations, we feel that creosote affords highly practical protection. Located a hardwood creosote at 55 cents per gallon that is highly recommended as a preservative and does not " burn " when splashed on hands or face.

Bought 50 gallons for wood walkways around Imhoff tanks: two coats to be applied when wood is thoroughly clean and dry.

June 10—Ordered 350 cubic yards of sand for re-sanding one battery of sludge drying beds. Fairly clean bank-run sand has been used successfully for this purpose for the past several years and was purchased, in this case, for $1.05 per cubic yard, delivered at the beds.

Re-sanding practice has been based on a three year cycle, with half the beds being done the first year, the other half the second year and none the third.

While ordering the replacement sand, a faint tint of green reflected our envy of Superintendent Hatfield at Decatur, Illinois, where combined sewage is treated and grit chambers are a necessary part of the plant. About 80 per cent of the grit received is sufficiently clean and well graded to use for replacement of sand lost at drying beds. Sand for this purpose has been purchased only once in 15 years of operation.

On second thought, we don't really begrudge Hatfield his economical sludge bed media. After all, combined sewers have so many unpleasant features that he's entitled to one advantage!

June 11—Severe electrical and rain storm interrupted power service for nearly three hours when a pole was struck by lightning and burned. Hats off to the power company's " minute men " who did a fine job in restoring service so quickly under the prevailing conditions.

June 19—Twin-dosing tank piping given a thorough flushing, the need of which has been evidenced by sluggish filter alternation the past few days. Replaced several elbows in the piping by tees and crosses to facilitate future flushing. The large amount of grease in this sewage necessitates frequent attention to the dosing tank piping.

June 27—Spent half the day discussing the benefits of sewage sludge as a soil conditioner with a local farmer. Were able to " sell " him on taking several hundred cubic yards as we remove it from the beds, thus saving truck hire by the District as well as stock pile space. Our care to point out the limitations of sewage sludge as fertilizer appeared to react favorably with the

"customer" by removing any doubt as to the advantages we claimed. He was also impressed by data and statements included in various articles on the adaptability of sewage sludge, contained in our file of **Sewage Works Journals.**

This experience raises the question, "Does it pay, in the long run, to overdo the sales talk on sewage sludge, with the result that the user is somewhat disappointed with results and doesn't come back?" We say it doesn't pay!

THREE REASONS FOR RELIABLE LABORATORY DATA AT AURORA, ILLINOIS

Reason Number 1—Sewage Sampling Bucket.—This bucket was designed for sampling channels and open tanks. Its construction is clearly shown in the accompanying sketch. When an ordinary bucket

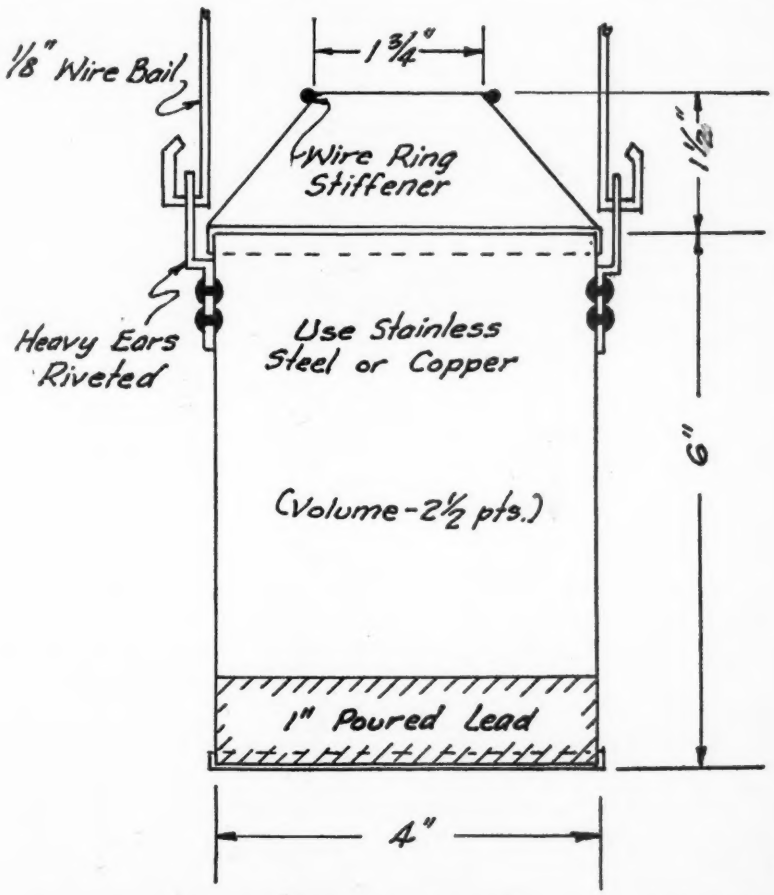


FIG. 1.—Sewage sampling bucket. Designed by Walter A. Sperry, Aurora Sanitary District.

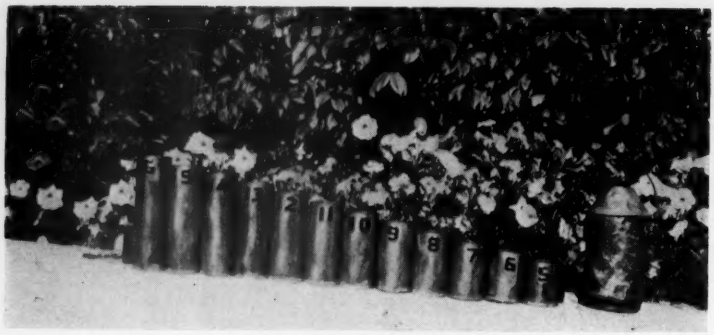


FIG. 2.—The Aurora "pipe organ" proportional sampling cans and the sampling bucket for open tanks and channels.

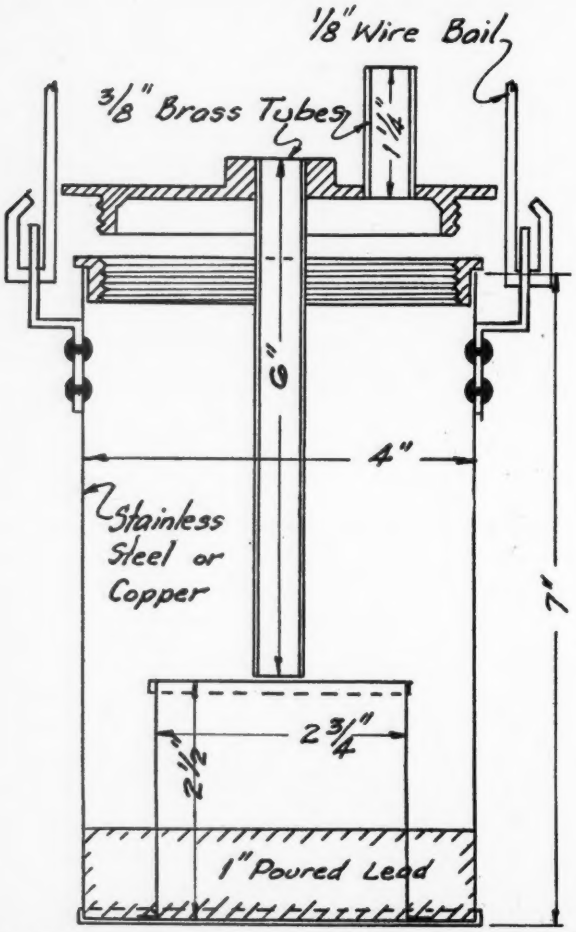


FIG. 3.—D.O. sampling can. Designed by Walter A. Sperry, Aurora Sanitary District.

or bottle on a stick is used the vessel is hard to sink and fills with a "gulp" at the surface.

This bucket sinks readily, and must fill slowly, allowing the bucket to be moved up and down through the sewage two or three times to fill, thus assuring an "average" sample.

Reason Number 2—Proportional Sampling.—The "Pipe Organ" Proportional Sampling Cans are useful where the flow is variable and 24-hour composite samples are collected. The cans are each 2½ inches in diameter and numbered by cutting out and soldering on large metal numbers. Since one-half inch represents 1 million gallons, the cans differ in depth by one-half inch. In use, the can selected for transfer of sample to the "composite" bucket corresponds with the Venturi meter reading for the hour the sample is taken. This plan avoids computation on the part of the operator.

Any other similar proportions can be used to suit local needs.

Reason Number 3—D.O. Sampler.—The special feature of this design for a dissolved oxygen sampler is the simple tight cover. In use it has been very satisfactory. The threaded ring and cover are obtained from a "Lead Drum Trap" which can be purchased from any plumbing supply house. The lid is drilled for soldering the tubes in place. The lead in the pot can be used to weight the bottom. The drum trap can be purchased for less than $2.50. The design is, therefore, much simpler than gaskets and toggle latches, which are hard to find.

THE MAINTENANCE OF SEWAGE TREATMENT WORKS EQUIPMENT *

By L. S. Kraus

Chemist, Peoria Sanitary District

Responsibility of Maintenance.—The management of the sewage treatment works has the responsibility of plant operation, personnel direction and plant maintenance. Of these responsibilities none is more important than the maintenance of the plant. Management has placed in its care many thousands, hundreds of thousands, and even millions of dollars worth of equipment; equipment which if properly cared for will serve the people of the community for a long period of time. It is the duty of the manager of the treatment works not only to operate the works properly but also to maintain the physical condition of the structures and equipment in the best possible condition. This is a public trust which every works manager should feel and respect. In addition proper equipment maintenance will improve works operation and reduced operating costs.

In general it may be said that prompt maintenance of operating equipment will save a large maintenance bill in the future. Where

* Presented at Second Sewage Operator's Short Course held at University of Illinois, March 10–14, 1941.

equipment cannot readily be shut down for long periods due to lack of spare equipment, prompt attention to minor repairs may result in eliminating the need for a major shut-down.

In addition to maintaining equipment in operatable condition, its appearance should be kept good. Proper cleaning and painting should be a part of the maintenance program. After a repair is made the work should not be considered finished until the appearance of the equipment is restored and this frequently may require some painting as well as cleaning.

Inspection Schedule.—The first step toward a good maintenance program is a regular inspection schedule, with much emphasis on the word regular. It is well to have a list of all of the equipment in the plant and to keep a record of inspections so as to eliminate uncertainities and to definitely tie inspection into routine maintenance duties. It is most difficult and unsatisfactory to trust memory for the performance of a duty, especially if done only once every six months. A record in some form is most imperative. An inspection interval should be set for each piece of equipment, possibly once each month for most of it.

The inspection does not necessarily consist of dismantling the equipment to determine its condition but may consist merely of a visual and auditory examination.

In our plant the operator who is designated as maintenance operator, makes the inspections and combines the inspection with infrequent maintenance duties such as grease lubricating motor bearings every six months or checking oil levels in air compressors. This operator makes out the inspection report and where repairs are necessary the method of doing the work and the order in which this work will be done is discussed with the management.

Maintenance Records.—If a piece of equipment does not appear to be functioning properly, that fact should be noted on the inspection schedule and a maintenance report made out. The equipment should then be thoroughly examined and repaired at the earliest opportunity.

The maintenance report is a useful record because it is not always convenient to work on equipment when the trouble is noted and it is easy to forget about things of this sort, especially if the trouble is of a minor nature. The report also serves as a record of the maintenance work done in the plant and is useful to determine the frequency of repairs and help point to the need of improvements to eliminate the trouble.

These reports are made out by anyone in the plant and cover minor items such as water leaks and lamp replacements, in addition to major repairs. The report is sent to the office and then given to the maintenance operator. After the repair is finished he describes the work done and the report is returned to the office for filing.

Record Drawings.—The need for detailed plans and descriptive literature for each piece of equipment in the plant cannot be overemphasized. For each device in the plant, from the largest structure to the smallest valve, complete drawings (if possible shop drawings)

should be on hand and well preserved. Together with these, repair parts lists and operating instructions should be filed. When a repair is contemplated the plans of the equipment should be studied in order to obtain a clear picture of the work involved or the nature of the repair work. If the dimensional drawings are available a part can often be reconditioned to its original dimension and the need for a new spare part may be eliminated.

Metals and Lubrication.—The need for repairs to mechanical equipment is brought about largely by abrasion and corrosion and it is desirable to have a reasonable knowledge of the properties of available metals in order to make intelligent repairs. In general, equipment manufacturers try to use the proper metals in their equipment; however at times they are not familiar with the specific application of their equipment and occasionally price competition may necessitate the use of materials which are not the most satisfactory.

In the treatment works the effects of corrosion and erosion may be minimized by the use of proper metals. The cost, strength, hardness, resistance to corrosion and machinability of the metal should be conconsidered for specific applications. Low carbon steels can be surface hardened by heat treatment for obtaining hard surfaces to resist abrasion, high carbon steels may be hardened throughout, or alloy steels may be substituted for ordinary mild steels where both resistance to wear and corrosion are necessary. The wearability of cast iron may be greatly increased by obtaining chilled castings.

Facing ordinary steels with special alloy steels by welding or spraying to obtain desired properties at low cost may be used. This phase of maintenance work is coming into greater use and because of the flexibility of the materials that may be applied considerable experimental work on the choice of materials may be done at low cost.

The proper lubrication of equipment is an important factor in the frequency with which repairs are necessary. In general the manufacturers will make recommendations regarding the lubricants to be used on their equipment. The oil companies will make a study of all of the equipment in the plant and prepare a chart indicating the oil or grease to be applied to the various mechanical devices in the plant. It is well to follow lubrication schedules closely and where possible to fix the responsibility for applying these lubricants on as few men as possible.

Electrical Equipment.—Practically all of the mechanical devices in the plant are electrically operated through control devices and motors. The electrical equipment is developed to a high state of perfection, however it must be properly maintained in order for it to give uninterrupted service.

The switchboard distributes power to the various plant units and houses the major circuit breakers and protective relays, contactors, controls and fuses. The entire switchboard should be given a monthly inspection and every several years all of the relay settings should be checked and properly adjusted. The latter usually requires expert

service which can be obtained either from the manufacturer of the switchboard equipment or from the local power company.

The contactors and magnetic switches require frequent inspection and care. The contactor consists of a solenoid mechanism which closes the contacts, usually of copper, with a combined rolling and wiping movement which insures a good contact and which on breaking causes the arc to form at the end of the contact. In addition the contactors above 110 volts A.C. are equipped with arc quenching devices. The wires that carry the current to the moving contacts are called shunts and usually consist of flexible braided copper wire. This wire is of very small diameter and is subject to rapid corrosion in the presence of hydrogen sulfide. The corrosion of shunt wires may be largely eliminated by the use of tinned copper wire in place of the plain copper wire.

Contacts on inspection will normally exhibit a somewhat roughened surface. If any small gobules of copper are found they should be removed, and when the contact area is pitted so that a small area of contact is obtained the contact should be replaced.

Oil should not be used in contactors, either on the contact or on bearings. Oil oxidizes and accumulates dust until the parts will not operate freely and may cause a discharge between the contactor or switch electrodes.

Care should be taken that heater protective devices are properly installed and that they are of the correct current rating for the motor or device protected.

The motors in the plant seem to be quite trouble free, however they can only be kept so by constant inspection and maintenance. Both sleeve bearing and ball bearing motors require periodic batch lubrication, the former with oil and the latter with grease. The danger of the motor hitting the stator winding must be guarded against by periodically checking the clearance between the rotor and stator.

Oil and dust accumulate on windings and tend to break down insulation to the point of ultimate burning out of the winding. When oil and dirt are found on stator or rotor windings they should be blown off with compressed air. If this fails to remove the deposit a volatile solvent such as gasoline or carbon tetrachloride should be applied. When a winding is washed with a solvent it is well to follow the washing with a coat of good insulating varnish. This should be done no more often than is necessary.

Moisture is the most dangerous condition to which motor windings are subjected. Motor windings exposed to moisture will ultimately burn out. The best corrective measure is to remove the wet condition possibly by properly enclosing the motor. Motor windings can be provided with special insulation to help resist moisture breakdown. When a motor is allowed to become wet it is well to have its windings dried with heat before replacing in service.

Motor collector rings and commutators together with their brushes should be kept in good non-sparking condition at all times. Proper choice of brushes for collector rings will result in practically trouble

free operation. Where possible use a carbon brush which has incorporated in it a mild abrasive, just enough to keep a polish on the collector ring.

Commutators are often a source of considerable sparking. Here again the choice of brush with a slight abrasive action is very beneficial. In addition an occasional dressing with resurfacing stones will maintain good operating conditions. It is necessary to have the commutator reground to a true cylindrical surface at times. This is best accomplished in the motor shop and, when this work is done, the mica insulation should be undercut.

A simple method of seating brushes is to apply an abrasive material to the commutator just ahead of the brush to be seated while the machine is rotating. The carbon, abrasive and copper dust should be collected in a vacuum cleaning device. The vacuum cleaner should also be used when grinding a commutator.

As in the case of contactor shunts all brush shunts should be of tinned copper wire.

Pumps.—The pumps of the treatment plant may be among the following types:

Piston Pumps.
Diaphragm Pumps.
Closed Shaft Non-Clogging Vertical Centrifugal Pumps.
Open Shaft Non-Clogging Vertical Centrifugal Pumps.
Open Shaft Screw Impeller Vertical Centrifugal Pumps.
Horizontal Centrifugal Sewage Pumps.
Horizontal Centrifugal Sludge Pumps.

The maintenance work on piston pumps is largely the maintenance of packing, pistons, bushings and bearings. The proper selection of a packing for piston pumps operating on primary tank sludge and digested sludge is of prime importance in the matter of keeping down maintenance costs. An improper packing will wear out quite rapidly and cause a considerable wear on the piston surface against which it is bearing. Our experience with Marlow sludge pumps indicates that the use of a Chevron type of packing which requires very little packing gland pressure is the most economical. By keeping the gland pressure at a minimum and providing piston lubrication with an oil such as steam feed cylinder oil this packing will last for one year on a pump operating practically continuously. After a year of operating some irregularities are apparent in the piston and before repacking the pump the piston surface is turned to provide a new smooth cylindrical surface. The piston is then packed with a larger width packing to take care of its reduced diameter. Bushings and pins on reciprocating parts require replacement and Babbit bearings require occasional adjustment.

Closed shaft centrifugal pumps are usually provided with a metal to metal seal between the rotating shaft and the pump housing. This is a source of considerable difficulty in the proper operation and main-

tenance of pumps of this type. Where the liquid handled is sewage or sludge it is well to provide a continuous feed of water into these metal seals in order that they may operate properly for a reasonable length of time. Sufficient water must be supplied to keep the grit from the sewage or sludge from getting into the metal to metal surface. Where the pump operates infrequently it is considered important to have these sleeves of a corrosion resistant material.

Many times the motor and pump of a closed shaft centrifugal pump are separated by a long shaft which requires intermediate bearings. These bearings are usually bronze bushings against steel sleeves on the shaft and are oil lubricated. These require little care providing the shaft assembly is in good alignment and the lubrication is faithfully maintained. If the seal at the bottom of the pump column leaks sewage or sludge the upper bearings must be protected from these liquids by providing an adequate drain in the pump column.

The pump impeller should be kept in a balanced condition and the proper clearance should be maintained between it and the pump housing in order that the pump efficiency and discharge be maintained. The impeller undergoes considerable erosion and some corrosion and the surfaces worn should be re-established either by welding or by the installation of replaceable rings. The same is true of the pump housing and where possible replaceable wearing rings should be installed when necessary and where this is not possible the clearance should be re-established by the addition of material applied with a welding torch and subsequent machining.

When reassembling a centrifugal pump, be sure that the key and keyway on the shaft and the impeller allow no appreciable play and that the impeller nut is tight and properly locked.

In open shaft pumps the seal between the shaft and the pump housing is made by means of a packing gland. Here again the choice of a proper packing material will determine the frequency with which packing is necessary. Usually pumps are provided with bronze bushings on the shaft which bear against the packing and these in all probability are to some degree lubricated by the admission of grease into the center of the packing gland. Here again much can be accomplished by water lubrication of the gland with an attempt to eliminating the possibility of sewage or sludge from getting into it. We have found in many cases that a hardened steel bushing on the shaft is more desirable than a bronze bushing. This is particularly true in pumps that are practically in continuous service. In pumps where operation is infrequent the corrosion resistant property of bronze or stainless steel is an important factor in the life of the packing. This type of pump may also require intermediate bearings on the shaft between the pump and the motor and these may be either the sleeve or ball type of bearing. It is absolutely necessary that the alignment on such a shaft be made with the utmost care in order for these bearings to give trouble free service. It is occasionally necessary to renew the rubber bushings commonly used in the couplings between the motor and the pump shaft.

Pump vibration due to an unbalanced impeller will greatly decrease the life of the coupling bushings.

Summarizing centrifugal pump troubles we must first keep the seal between the rotating shaft and the pump housing from leaking and we must keep the pump impeller and pump housing in such condition that the clearance between the housing and the impeller be maintained. In addition it is necessary to keep the impeller in such condition that it will be properly balanced and maintain its original dimensions. The key and keyway must fit properly and the impeller nut must be adequately locked in place.

Piping, Valves and Meters.—From the maintenance standpoint the piping, valves and meters of a plant require relatively little attention. Where materials for pipe and valves are properly chosen little corrosion or wear may be experienced. Wherever possible valves should be either completely open or closed, especially when handling an abrasive liquid such as sludge. Where gate valves are partially open very high velocities under the valve gate will cause erosion of the gate and seat and the valve will wear out very rapidly. In gas lines where hydrogen sulfide is encountered, valves should be of all iron construction with stainless steel stems. The greatest trouble with valves and sluice gates is due to corrosion of the moving parts when the valve is inoperative. It is not necessary to use certain of the valves and sluice gates in the treatment works but once every several years, however these should be operated once about every six months and should be kept coated with a film of rust inhibiting grease in order that the valve or gate will operate when it is necessary that it be used.

Mechanical Devices.—Mechanical devices for collecting and grinding screenings, collecting grit, and collecting sludge and scum are mechanisms that require regular attention and periodic repairs.

The comminutor, a screenings grinder, requires frequent replacement of the cutting parts, namely the cutters, shear bars and combs. The cutters can be sharpened by grinding and reinstalled. The combs and shear bars should be replaced when they are dull.

Many mechanically cleaned screens depend on a hoist or chain for their operation. A hoist operated screen cleaner requires some attention. The cable should be protected with a rust inhibiting grease and the brakes must be kept in good working order. Chain operated screens require the usual care needed by chains operating in sewage. The control devices on mechanically cleaned screens must be kept in good operating condition.

The chain operated grit and settling tank mechanisms undergo considerable wear. The chain is usually of hardened malleable iron links with hardened steel pins. The chain is sewage lubricated and the grit in the sewage which is quite abrasive causes it to wear. After several years of service it is possible to turn over the chain and use the unworn link surfaces. The pins and pin sockets will be worn and the pitch of the chain will be increased. The sprockets may be reversed providing the pitch of the chain has not changed appreciably.

In addition to the chain and sprocket wear these mechanisms have wearing shoes, which carry the chain and flight load, and which wear very rapidly. These may be of a hard, tough material such as manganese steel and they may bear on a mild steel rail of rectangular or I section. The wearing shoes require replacement when they wear sufficiently to allow the flight to touch the tank bottom. They may be built up by welding with air hardening steels or they may be replaced with such hard casting as chilled cast iron or high silicon and manganese cast iron. Screw conveyors used to elevate the grit from the tanks wear above the water line to a sharp knife edge. This may be repaired by welding a rectangular rod of small section to the worn surface. This is done but once every eight to ten years. The chain life is in the order of ten years and the wearing shoe replacement is made from a year to year and one-half.

Grit and settling tanks operated by traction driven rotating plows have several points requiring attention. The drive wheel which rides on the rail wears slowly, especially if it is made of hardened steel or chilled cast iron, however after many years it requires either replacement or rebuilding of the wearing surface by welding with a hardened steel rod and subsequent grinding. The guide wheels wear rapidly and may either be replaced or be provided with hardened steel tires which can be pressed on the original casting. It is difficult to provide a tire of moderate thickness to the drive wheel because of the tendency for it to creep on the wheel.

Little difficulty is encountered in oil immersed closed case worm gear speed reducers, however when open worm gear and bull gears are used for speed reduction much care must be exercised to provide good lubrication by the use of an adhesive grease and also to provide accurate gear alignment. When gears are misaligned the worm gear, usually of bronze, will wear out rapidly and probably cause some wear on the cast iron bull gear. If the latter gear is not too badly worn it may be reconditioned by careful grinding of their gear bearing surfaces. Gears are difficult to replace in local shops and must usually be purchased from the equipment manufacturer.

Summary

The plant manager wields the guiding hand that determines the life and efficiency of the plant equipment. The public has placed a trust in him to preserve and operate this equipment so that it will return to them the greatest possible service. The plant manager must feel his responsibility and respect this trust. In return for public confidence the manager must do everything possible to maintain the plant equipment in good working condition and appearance. By so doing the equipment will always be ready to use and the cost of maintenace reduced.

For the manager's conveniece inspection and maintenance reports should be made and preserved. Record drawings, parts lists and operating instructions on all plant equipment should be kept on file.

Maintenance work may be done by use of the equipment manufacturers parts service or the use of local machine and welding shops for the building or rebuilding of the parts required.

BUFFALO'S LABORATORY MOTTO

The following remarks were afforded by Chief Chemist G. E. Symons in acceptance of the Kenneth Allen Memorial Award which was presented to Dr. Symons and William L. Torrey by the New York State Sewage Works Association for their paper entitled "Buffalo River Stream Pollution Studies 1936–1939."

In accepting this award, I do so not only for myself and Mr. Torrey, but also on behalf of the entire staff of the Bird Island Laboratory, without whose assistance the collection of the large amount of data represented in the paper would not have been possible. We, and all of the members of the staff associated with me are deeply appreciative of this honor.

In answer to a comment not to take ourselves too seriously as a result of this Award, perhaps we should take from our files a quotation typed on a small card and place it beneath the plaque to remind us again of the proper humility. That remark, which once put us in our proper place, was made by an eminent consulting engineer of this country after visiting our newly equipped laboratories, to the effect that, "If good equipment is all that is required for success, the Bird Island Laboratory should become famous." We have that comment filed under the label, "Anti-big Head Department."

As a matter of fact, the motto of our laboratory has remained the same since its inception in April, 1936, in spite of the transition from small temporary quarters to a large modernly equipped laboratory. That motto is taken from the novel *Arrowsmith,* by Sinclair Lewis. You may recall that Arrowsmith had conducted some research in his kitchen with a tea kettle and broken crockery for equipment, and for his efforts had been sneered at as a "cow-doctor." Doctor Gottlieb, the director of the great research laboratory, bolstered the downcast Arrowsmith with these remarks, "If a man cannot build a laboratory from two toothpicks and some pieces of string, let him buy his fine results along with his fine equipment."

That is our motto. Although equipment is essential to good work, fundamentally we believe it is the attitude and the willingness of the worker to do something himself that produces the most worthwhile results. In accepting this Award in recognition of some of our work, I assure you that we shall continue to approach our studies with the

humble attitude of searching for the truth, an attitude that we must give of our own efforts, and not depend on either past honors or fine equipment to solve the problems of the future.

SHORT, SHORT STORY

Creek polluted
Town law-suited
P. W. A.
Creek O.K.
(The End)

Editorial

SAVE OUR STREAMS

It seems inevitable that, as industrial activity speeds up and defense production takes precedence over all other manufacturing objectives, the discharge of industrial wastes increases, streams become more highly polluted, and stream sanitation is ignored or forgotten. In times of depression some headway is made against industrial waste pollution, but when industry is busy and production must be pushed to the limit, no effort is made to carry into effect the methods of abatement that were developed in less feverish times, and untreated wastes are discharged to streams in increasing volume and strength, with no attempt to reduce the polluting constituents. Efforts by state or governmental agencies to cope with this situation seem to be rather futile, as industry is either too busy, too harassed, or too callous to make proper provision for disposal of wastes.

New industries also are being established on many waterways, particularly industries which contribute to national defense. The colossal munition and ordnance plants that are being built create especially difficult problems of stream sanitation. All types of industry are overwhelmed by the necessity for speed in production, and existing plants must be pushed to capacities beyond those contemplated in the original design. It is generally true that the strength of industrial wastes greatly increases when production is pushed past comfortable levels. Not only does the overall volume increase in proportion to the increase in production, but the unit losses of polluting constituents also increase alarmingly after the limit of normal production is exceeded.

Some of the industrial waste problems are staggering. For example a munitions plant in Indiana expects to discharge more than 60 tons of sulfuric acid per day, enough to turn the entire Ohio River acid if uniform discharge of wastes is not carefully controlled in relation to stream flow. Another plant in Illinois may turn the Illinois River acid at times and add oxygen-demanding solids of considerable magnitude. The rivers in the East are also subject to greatly increased pollution. The busy Raritan Valley, in which considerable progress has been made to abate industrial pollution, should not again be allowed to deteriorate to a foul and nauseous condition. The Connecticut, Naugatuck, Delaware, Passaic, Cuyahoga, Scioto, and Ohio Valleys, noted for industrial concentration, should at least be held in status quo, with reference to industrial waste pollution. The picturesque Kanawha Valley is humming with activity of great chemical plants, which pour wastes with hundreds of thousands of population equivalent into this fair stream.

Large cities also feel the effect of industrial expansion. In Chicago there was a notable increase of industrial waste load in the latter part

of 1940 and this continues, to the detriment of the condition of the upper Illinois River.

What is to be done about this situation? Time is too short to head off most of the increase of industrial waste pollution, but there is still time for industries to attempt to minimize the discharge of wastes by intelligent study of processes within the factory, followed immediately by measures for reducing or eliminating the most undesirable wastes. All large plants should establish a division of waste prevention, consisting of a chemist and an engineer, with adequate assistants and laboratory facilities for surveying the waste-producing processes within the plant. The most objectionable wastes should be selected for intensive study, first to determine whether some other process might be used which would not produce such objectionable wastes; if this is impossible, a study of recovery or destruction of the objectionable constituents should be undertaken; the worst wastes should then be compared and classified as to the cost of elimination, and money should be spent on those wastes where the greatest reductions of B.O.D., suspended solids, or bacteria can be obtained for a given expenditure. The river requirements will of course determine which type of reduction is most urgent.

This is the initial step that should be taken by all large industries if they expect the sanitary authorities to have any confidence in their intentions to relieve pollution. It will usually be profitable for the industry to retain a consulting sanitary chemist or engineer to supervise this sort of work, because the plant chemical engineers or mechanical engineers generally have little conception of the methods and objectives of stream-pollution prevention. After the proper start, however, the plant experts are usually quite able to carry on alone, with only occasional outside help.

In addition to this type of investigation and amelioration of wastes within the plant itself, it is helpful to have investigations of waste treatment by trade associations, such as those that have been carried on by the Textile Foundation, the dairy industry, the tanning industry, the steel industry, etc., but in the end the general conclusions of these investigations have to be applied to specific plants, therefore time can be saved and a more satisfactory solution can practically always be accomplished by a group of experienced men working within the individual plant, under proper guidance by the state sanitary engineer's staff, or by some qualified expert.

All large industries must be made to realize the necessity for some such procedure as this if we are to save our rivers from a sudden and deplorable influx of pollution that may destroy their natural beauty and usefulness for many years to come.

F. W. Mohlman

Proceedings of Local Associations

SEWAGE DIVISION TEXAS SECTION, S. W. W. A.

Twenty-Third Annual Meeting

Texas A. and M. College, February 17–21, 1941

The Sewage Division of the Texas section, S. W. W. A., and the Texas Water Works and Sewerage Short School held their twenty-third annual meeting at A. and M. College, College Station, Texas, during the period February 17–21, 1941. The attendance at these Short Schools has been steadily increasing each year and this year's registration showed a record attendance of 300 members and guests.

The program was divided into three sections—water, sewage, and laboratory. All of the sections were well attended and there was excellent participation in the various discussions on mutual problems. Special emphasis was placed this year on the National Defense Program and its relation to the water works and sewage fields. Interest continues in the treatment and disposal of industrial wastes and particularly the discharge of salt water from oil wells since it is becoming a problem of great concern all over the State.

Monday evening a new feature was introduced into the program in the form of "Special Coaching Session" on the examinations for various grades of licenses for both water and sewage plant operators. Prior to dismissal of the group to separate classrooms, there was a general discussion of certain features of the licensing program which needed clarification and in some instances slight revision. In the classrooms, a general outline of the subjects to be covered by the examinations was presented and the operators were given an opportunity to request such items as they desired to have explained in greater detail.

On Tuesday evening there was a joint meeting of the eighteen district water works and sewage associations in the State each of which was represented at this session. Three new district associations have been organized since the last meeting. The program was in the form of a round-table discussion and the officers of the various associations reported on the type of publicity used for their meetings, special speakers, outlined study courses and entertainment offered. During the year Mr. Lewis Dodson of the State Department of Health and Messrs. David Smallhorst and H. D. McAfee of the Industrial Extension Training Service at A. and M. College, have prepared a year's study course for these groups furnishing outlined lecture material as well as slides and films for illustration purposes. The associations expressed their gratitude for this material since most of them have already put this study program into effect and have found it most beneficial to the members.

The Committee appointed at last year's session to select a design of a pin for the licensed water plant operators and secure quotations on prices, made a report to the group. Several designs were presented and the group voted in favor of a "shield design" in gold with the lettering "Texas Water Supply Operator" with a star in the center on which is placed the Grade A, B or C. These pins are to be ordered through, and distributed by, the district secretaries. Mr. Bob Gresham, Editor of the *Southwest Water Works Journal,* spoke to the group and offered the Journal as a medium of publicity to all the district associations and outlined the manner in which such publicity should be presented.

Wednesday evening a special demonstration on plumbing and cross-connections was presented by Mr. A. A. Peary, chief plumbing inspector of Houston, and Mr. G. C. Anders, Secretary of the Master Plumbers Association of Texas. After this demonstration another coaching session was held for the operators desiring to take the Grade A examination for a Water Supply Operator's License. Another group met for a special conference to discuss the minimum standards of pollution set up in a proposed bill which Representative Fred V. Klingeman had submitted to various water works and sewage officials throughout the State. The discussion brought out the desirability of clarifying the definition of the term "pollutant" and making the application more flexible to meet varying conditions. A suggestive outline of principles for stream pollution control work was prepared and submitted to the entire membership for adoption.

The annual banquet was held on Thursday evening. In the absence of the President, the First Vice-President, Mr. S. C. Clark, presided. Dr. George W. Cox, State Health Officer, was the principal speaker and reviewed the progress that had been made in the water works and sewage fields during 1940. Dr. Cox made special reference to the relation of these utilities to National Defense and industrial growth of the State. The Honor Roll of Texas cities for outstanding achievement was read by Dr. Cox and special trophies were awarded to (1) City of Fort Worth for having maintained the best sewage effluent during 1940, (2) City of Uvalde for having made the greatest improvements in their sewage plant, and (3) City of Hamlin for having made the greatest improvements to their water treatment plant.

Mr. Ashley G. Classen, Chairman of the Resolutions Committee, presented a report which was unanimously accepted by the membership. Of particular importance were resolutions adopted with reference to the desirability of a uniform State Plumbing Code, minimum standards relating to the pollution of Texas streams, and advantages to be derived from the creation of Sanitary Districts.

Mr. J. L. Horner, Chairman of the Committee on Awards, presented a report which included the following awards:

1. A plaque to the Rio Grande Valley Water Works and Sanitation Association for having the greatest number of members attending the Short School and who had travelled the greatest number of

miles. Since the Rio Grande Valley Association has won this award for three consecutive years, the plaque is to remain in their possession permanently.

2. Honorary Life Memberships in the organization were presented to Professor E. W. Steel of A. and M. College and D. B. Dickson of Wichita Falls. This award is based on outstanding service to the Short School.

3. Honorable mention was given to those cities which had secured the greatest decrease in insurance key rates during 1940 and a licensed water plant operator in charge of their plant.

Mr. A. R. Kennedy, Chairman of the Auditing Committee, presented the financial report of the organization.

The Committee on Certification of Sewage Plant Operators presented their report which also indicated a considerable increase since last year. This Committee suggested a revision of the experience qualifications and educational requirements for the various grades and also included credit hours for training courses attended.

Mr. J. L. Swanson presented the report of the Nominating Committee and the following officers were unanimously elected to serve during the coming year:

President ..... S. C. Clark, San Benito
First Vice-President ..... M. J. Salmon, Commerce
Second Vice-President ..... Roy Matthews, Albany
Third Vice-President ..... W. F. Hicks, Paris
Fourth Vice-President ..... J. C. Stegall, Seguin
Secretary ..... V. M. Ehlers, Austin
Asst. Secretary-Treasurer ..... Mrs. Earl H. Goodwin, Austin

On Friday afternoon examinations in all grades were conducted for both water and sewage plant operators desiring to secure licenses. This session closed the Short School for 1941 and it was the consensus of opinion of the attendants that this was one of the best schools which had ever been held.

A new feature introduced as a part of the Short School this year was a one week special laboratory training course preceding the regular sessions. Since facilities for this training course were somewhat limited, each district association was given the privilege of selecting one of their group to take the course. Dr. C. H. Connell of A. and M. College conducted the classes and was ably assisted by Messrs. Smallhorst and McAfee of the Industrial Training Bureau. These classes included the various laboratory tests in connection with the operation of water and sewage plants. Those who attended this special training course in laboratory procedure expressed their gratitude for the opportunity and indicated that they had derived some very valuable information and training. Certificates were issued to those successfully completing the course: namely, Mrs. Edna Archbell, Marshall; J. D. Burke, Graham; W. E. Cuzick, San Angelo; B. P. Dake, Gladewater; J. B. Daniel, Robstown; Bradley L. Guthrie, Brownwood; H. Hagood, Jr., Austin; Fran-

cis Hamlin, Laredo; E. C. Johnston, Jacksonville; N. S. Meyer, Big Spring; I. N. Ronhovde, Olney; J. C. Stegall, Seguin; G. L. Straughan, Crockett; T. Clifford Tudor, Beaumont; and J. F. Williams, Waco.

Requests have already been received from numerous members who wish to take this course next year. It is hoped that facilities will be available to take care of an increased number of laboratory personnel next year.

MRS. EARL H. GOODWIN, *Assistant Secretary*

KANSAS WATER AND SEWAGE WORKS ASSOCIATION

Thirteenth Annual Meeting

Lawrence, Kansas, March 13–15, 1941

The thirteenth annual meeting of the Kansas Water and Sewage Works Association was held on March 13, 14, and 15, 1941, in Marvin Hall, at the University of Kansas, Lawrence, Kansas.

The first session was called to order by President Robert Peart at 10:00 A.M. on March 13, at which time the report of the Secretary, Earnest Boyce, Chief Engineer, Kansas State Board of Health, was read. In addition to the routine business of the Association, this report dealt with the reorganization of the Federation of Sewage Works Associations in relation to the Kansas Association. Changes in the Constitution of the local organization were necessary in order to conform with the Constitution of the Federation. The Constitution was revised and the revisions ratified by a unanimous vote of the members present at the conference. Copies of the revised Constitution were distributed to all those who attended. The total registration for the meeting was 100.

In addition to numerous interesting papers on water supply and treatment, the program contained several informative discussions on the theory and practice of sewage treatment and related subjects.

C. C. Ruchhoft, Principal Chemist, Stream Pollution Investigation Stations, U. S. Public Health Service, led the sewage treatment discussion with a highly interesting paper entitled "Dissolved Oxygen and B.O.D. Determinations, Their Application and Interpretation." This paper was followed by a film showing a few of the activities of the Stream Pollution Investigation Stations of the U. S. Public Health Service. Interest in Mr. Ruchhoft's paper was evidenced by the numerous requests for mimeographed copies.

Murray A. Wilson, Consulting Engineer, made an important contribution to the program with his talk on "The Design and Operation of Sewage Treatment Plants." Mr. Wilson's paper was enhanced by the use of slides showing many Kansas sewage plants in operation and in various stages of construction.

"Biochemical Purification by Activated Sludge" was the title of

Mr. Ruchhoft's second paper, which dealt with fundamental studies relating to the activated sludge process.

During the informal discussion period, questions of safety in water and sewage plant operation were considered and discussed by the various members. Numerous other topics, all relating to water supply or treatment were also discussed.

Of particular interest to operating personnel was a paper given by G. R. Herzik, Jr., Chief Engineer, Bureau of Sanitary Engineering, Texas State Health Department, on "The Value of Voluntary Licensing of Water and Sewage Works Personnel."

The annual banquet was held the evening of March 14 at 6:00 P.M. in the Kansas University Memorial Building. Following the dinner, a short musical program was provided by University students. This was followed by a business meeting and the showing of two films, one dealing with the Ohio River Pollution Survey now being conducted by the U. S. Public Health Service, and the other with the industrial and agricultural development of Kansas. W. H. Wisely, Executive Secretary of the Federation of Sewage Works Associations, gave a short talk on the Federation and explained its aims and functions in relation to the local association.

On Saturday, March 15, a group of 25 members assembled at Marvin Hall, University of Kansas, at 8:30 A.M., and then left by car for visits to water purification plants at Ottawa, Iola, and Chanute, Kansas, and the sewage treatment plant at Garnett, Kansas. The group reached the Chanute plant about 1:00 P.M., where an excellent luncheon was served through the courtesy of the city of Chanute.

New officers of the Association were elected as follows: Sol F. Kunz, Emporia, *President;* R. B. Reeves, Chanute, *Vice-President;* M. E. Rogers, Wichita, *Vice-President;* Perry M. Keller, Liberal, *Vice-President;* and Glenn G. Patterson, Ellsworth, *Vice-President.* Earnest Boyce continues as *Secretary-Treasurer.*

Prior to the regular Association meetings, a special three-day laboratory school was held. Instruction was given in the water and sewage laboratory of the Kansas State Board of Health, University of Kansas, Lawrence, Kansas. Instructors who participated in the presentation of the course of material were: Cassandra Ritter, Bacteriologist; E. O. Holmes, Chemist; and Paul Haney, Chemical Engineer, all of the State Health Department; and Robert Hess, Chemist, Municipal Water Department, Wichita, Kansas.

Topics discussed included coagulation, taste and odor control, chlorination, and microscopic organisms. The laboratory work consisted of alkalinity, hardness, chlorine and pH determinations, and microscopic examinations.

Films shown as a part of the instruction program included one dealing with microscopic life in Texas waters, and one on the various phases of operation of a complete water treatment plant.

Eighteen plant operators, chemists, and engineers attended this special school.

EARNEST BOYCE, *Secretary*

ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

Fifteenth Annual Meeting

Yuma, Arizona, March 21–23, 1941

The Arizona Sewage and Water Works Association held its fifteenth annual meeting in Yuma, Arizona, on March 21, 22, and 23. The meeting was a joint session with the members of the California Sewage Works and California Water Works Association.

After a business session on Friday morning March 21, the technical program was opened with A. W. Miller, President, presiding. A discussion on "Repairs in a Small Water Works System" was presented by Guy A. Rhoads, Supt., Municipal Utilities System, of Safford. This was followed by a discussion of the Yuma Water Works by C. G. Ekstrom, Manager, Arizona Edison Co., of Yuma.

At the noon luncheon where eighty delegates attended, Ray F. Goudey, Sanitary Engineer for the Dept. of Water and Power, of Los Angeles, presented an illustrated paper on the "Development of New Zeolites."

During the Friday afternoon session, there were 50 to 75 delegates in attendance, when E. W. Daley, City Manager of Tempe, outlined his experiences on the "Operation of a Dunbar Filter Plant." "Protective Coatings for Sewage Plants" was presented by Dario Travaini, Supt., Sewage Disposal Plant for Phoenix. A complete, and most comprehensive paper was presented by W. J. O'Connell, Jr., Wallace and Tiernan Sales Corp., San Francisco, on "Programming Chlorination for Best Results." "Bearings and Maintenance of Electric Motors" was the title of the instructive talk presented by John R. Read, Westinghouse Electric Mfg. Co., of Phoenix.

The dinner meeting on Friday night was one of the best attended in the history of the Association to this date. One hundred and twenty delegates and their wives heard a discussion of the "All American Canal Project" which was an illustrated lecture, by L. J. Foster, Construction Engineer, U. S. Reclamation Service, Yuma. W. H. Westover, City Attorney of Yuma, presented a discussion on the "Public Relations Man in Your Utility Plant." A. M. Rawn, life member of the Association, awarded certificates of registration to 20 operators who had completed the necessary examinations for the certificates.

At the morning session on Saturday March 22, J. Ed. Miller, City Manager of Tempe, presented a series of moving pictures on the "Mesa Federal Aid Project." This was followed by a discussion by Cavett Robert, Vice-President of the Arizona Edison Co., Douglas, on "Telling the Water Works Story to Non-Technical Folks." Dr. J. A. Montgomery, of the Lakeside Engineering Co., of Chicago, Illinois, presented a discussion of "Complete Sewage Treatment." A. M. Rawn, Chief Engineer and General Manager of the Sanitation Districts of Los An-

geles, furnished the Association a "Report on the Formation of the New Federation of Sewage Works Associations."

At the noon luncheon on March 22, W. W. Hurlbut, Asst. Chief Engineer, and General Manager of the Dept. of Water and Power of Los Angeles, provided a discussion to the 90 in attendance, on "A Common Ground for Water Works Development."

Following this discussion, Ray F. Goudey, Sanitary Engineer for the Dept. of Water and Power, was presented with a life-certificate by the Association. M. R. Tillotson and A. M. Rawn are the only other life members of the Association. Because of unusual service these men have rendered the Association, through their high offices, these life memberships are offered at rare intervals. Participation in programs, advice and assistance to the Association, high quality of leadership, encouragement to operators through friendly helpful advice, consistent interest in the Association, and other qualities mark the man for life membership in the Association.

During the afternoon session, A. M. Rawn conducted a round table discussion. This discussion revolved around zeolites in water treatment, all manner of water works problems, discussion of the papers presented on the program, and various affairs of the Association. The round table was stopped only when it became so late that it was necessary to adjourn to prepare for the evening's barbecue.

The barbecue in the evening and the dance following were attended by all delegates, their wives, and a number of local guests. More than 150 persons were served. This was one of the most successful features of the program.

Sunday morning, after inspecting the Yuma water treatment plant, 27 cars, filled with delegates, went on a trip to Imperial Dam and the All-American Canal Desilting Works. At the Dam, boat rides, side trips, etc., were provided. A picnic lunch was served to the members of the Association and their guests by Boy Scout Troop 56 of Yuma. Following the luncheon the trip was continued by 14 cars to inspect the Upper Gila Irrigation Project, and the Arizona Minerals Corporation plant where zeolite is manufactured.

There were 91 delegates and 22 wives registered at the convention, 76 of the total of 113 were from Arizona, 36 were from California, and 1 from Chicago.

The new officers elected for the following year were:

President, Guy A. Rhoads, Supt., Safford Municipal Utilities.
First Vice-President, Geo. W. Seeley, City Manager, Tucson.
Second Vice-President, Richard Bennett, Water Supt., City of Phoenix.
Secretary-Treasurer, F. C. Roberts, Jr., State Sanitary Engineer, State Board of Health, Phoenix.

Board of Directors:

A. W. Miller, Johns-Manville Corp., Phoenix.
P. J. Martin, Jr., Water Supt., Tucson.
A. L. Frick, Jr., Wallace and Tiernan Corp., Los Angeles.

Cavett Robert, Vice-President Arizona Edison Co., Douglas.
H. D. Hall, Disposal Plant Supt., Grand Canyon.
Bernard Schiller, Yuma County Sanitary Engineer, Yuma.

F. C. ROBERTS, JR., *Secretary*

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Spring Meeting

Boston, Massachusetts, April 3–4, 1941

The spring meeting of the New England Sewage Works Association was held jointly with the New England Health Institute and the New England Water Works Association on April 3 and 4, 1941, at the Hotel Statler, Boston, Massachusetts. A total of about 175 members and guests of the New England Sewage Works and New England Water Works Associations attended the meeting.

No reports were submitted by the secretary and treasurer for this meeting. A meeting of the executive committee was held during the afternoon of the first day. At this meeting the use of safety code placards for individual sewage treatment plant structures was discussed. The president was authorized to appoint a committee to study operators' salaries and a progress report was accepted by Mr. Trager's committee on the advisability of this Association editing its own journal. It was decided by the executive committee that the trend of articles in the Federation *Sewage Works Journal* would first be ascertained before definite steps were taken toward publication of our own journal. It was felt by the members of the executive committee that more articles on practical plant operation should be published in the Federation journal. It was also decided to hold the annual fall meeting in Providence, Rhode Island, probably on October 1 and 2, 1941.

Following is a list of the papers and their authors as presented at this meeting:

Military Field Sanitation by Col. William A. Hardenbergh, Sanitary Corps, U. S. Army.

Transmission of Diseases and Poisons Through Water

(*a*) Bacteriologic Phases by Prof. W. LeRoy Mallmann, Professor of Sanitary Bacteriology, Michigan State College.

(*b*) Toxicology by Dr. Lawrence T. Fairhall, Principal Industrial Toxicologist, National Institute of Health.

Development and Operation of Sanitary Personnel for National Defense by Col. John J. Reddy, U. S. Army, Capt. Joseph J. A. McMullen, U. S. Navy, Ralph E. Tarbett, U. S. Public Health Service.

Development of Water Supply and Sewerage for 30,000 Troops at Camp Edwards by Samuel M. Ellsworth, Consulting Engineer, Boston, Mass.

Emergency Protection of Public Works and Utilities by William W. Brush, Editor, *Water Works Engineering.*

Sanitary Problems in the Vicinity of Troop Areas by Walter D. Tiedeman, Chief, Bureau of Milk Sanitation, New York State Department of Health.

A joint luncheon was served the New England Sewage Works Association and the New England Water Works Association in the Georgian Room of the Hotel Statler at 1:00 P.M. on April 3.

On Friday, April 4, there was an inspection trip to Fort Devens to examine the sanitary and other works of the fort. An informal luncheon was held at the Groton Inn following the inspection.

LeRoy W. Van Kleeck, *Secretary-Treasurer*

Reviews and Abstracts

SOME EXPERIMENTS ON PRECIPITATION OF A TRADE WASTE SEWAGE

By C. Lumb and J. P. Barnes

The Surveyor, 98, 239–240 (Nov. 15, 1940)

Forty per cent of Halifax sewage is trade waste, composed principally of textile wastes of a soapy and greasy nature. Consequently the sewage is highly colloidal in character.

For many years sulfuric acid has been used for grease recovery. Optimum precipitation with acid is obtained at a pH value of 3.2 ± 0.3. The high cost for the acid used led to experiments with other standard precipitants. Nothing as effective as "aluminoferric," *i. e.*, commercial hydrated aluminum sulfate, was found. Investigation showed that addition of 5 to 20 parts of aluminoferric, in conjunction with acid, shifted the pH value for optimum precipitation towards the neutral. Considerably less acid was required with the combined precipitants than with acid alone.

The authors conclude that for the sewage investigated the cost of additions of 5 to 10 parts (per 100,000) of aluminoferric are more than counterbalanced by the corresponding saving in acid giving a more economical combination than acid alone.

K. V. Hill

WET MILLING OF CORN RECOVERY AND UTILIZATION OF PROCESS LOSSES

By A. L. Pulfrey, Ralph W. Kerr and H. R. Reintjes

Ind. and Eng. Chemistry, 32, 1483 (Nov., 1940)

Prior to 1920, the total process losses after recovery of solids by evaporation from the countercurrent water used in the steeping operation, amounted to 2 per cent of the total dry substance ground at the Argo Plant of the Corn Products Refining Co. The pollution load of the entire factory waste amounted to some 400,000 population equivalents per day.

Recirculation of the process waters originating from starch washing and gluten settling and concentrating them with steep waters in the vacuum evaporators was effective in reducing the pollutional load. These changes in conjunction with the recirculation of the starch and gluten wash waters and the establishment of a "process losses" department to obtain closer control over solids losses resulted in reduction of the population load to between 50,000 and 100,000, by 1928. Further reduction in the pollutional load was affected by venting the organic vapors from the second and third effect heaters to the barometric condenser on the third effect and pumping them directly to the atmosphere by means of a steam jet.

Study of the constituents in steep water vapor revealed that 75 per cent of the volatile portion was ethyl alcohol. The authors have devised a method of recovering this alcohol profitably and at the same time reducing the pollutional load to between 10,000 and 20,000.

E. Hurwitz

UTILIZATION OF WASTE PRODUCTS RECOVERY PROCESSES: SALVAGE IN THE CHEMICAL INDUSTRY

The Surveyor, **98**, 341 (Dec. 27, 1940).

The 1940–41 joint meeting of the Chemical Engineering Group of the Society of Chemical Industry, and the Institution of Chemical Engineers occupied itself largely with discussion of the salvage of waste materials. The assistant controller of Salvage, Ministry of Supply, stated that the problem involved either a use for a waste material which accumulated as the result of some process, or the recovery of a valuable material from a waste product.

Recovery of wool grease was cited as an example of salvage. In the Bradford area some 14,000 tons of grease per year was recovered, about one-third of this amount by the woolcombers themselves and two-thirds from the city sewage. The "straight" grease was worked up into products such as lanoline, lubricating greases and paints. The grease recovered from sewage was being processed for use in camouflage paints and anti-corrosive metal coatings.

Greater use of sewage and sludge for fertilizers was also urged. Attention was also directed to the need for improved methods of dehydration to permit recovery of chemicals from sewage.

K. V. Hill

WASTE SULFITE LIQUOR—SEWAGE MIXTURES ACTIVATED SLUDGE TREATMENT

By C. N. Sawyer

Ind. and Eng. Chemistry, **32**, 1469 (Nov., 1940)

Public demand that measures be taken to alleviate the conditions in streams caused by disposal of waste sulfite liquors led to investigation of treatment of these wastes by the activated sludge process.

The initial experiments were carried out on effluent from the Howard process having a 5-day B.O.D. of 11,700 and pH 8.0. Sulfite waste was fed to the sewage-sludge mixtures in quantities of one per cent until the desired concentration was reached. Mixtures containing from 8 per cent or less waste showed reductions of 94 per cent B.O.D. Mixtures containing 6 per cent or more of sulfite liquor produced dense sludge which could not be kept in suspension with normal amounts of air. The increased density of the sludge was due to deposition of calcium carbonate in the activated sludge. To avoid this the pH of the sulfite liquor was adjusted to pH 8–9 before feeding.

B.O.D. of Effluent from Activated Sludge Treatment of Waste Sulfite Liquor—Sewage Mixtures—Aerated 22 Hours

Per Cent Waste Sulfite Liquor	B.O.D. on Various Days of Feeding Exp.					Av. B.O.D. of Feed, P.P.M.	Av. B.O.D. Removal, Per Cent
	2nd	3rd	4th	7th*	14th		
2	19.5	18.3	18.4	23.0	22.4	430	95.3
4	32.0	37.0	37.4	44.2	31.5	670	94.4
6	48.4	49.0	48.0	58.5	47.3	920	94.5
8	68.0	68.5	73.0	85.3	74.0	1150	93.6
10	86.2	87.0	87.5	125.0	82.0	1400	93.2

* Aerated 16 hours.

Experiments with a magnesium base sulfite liquor showed a tendency to bulk when more than 2 per cent of the waste was used. B.O.D. removal was very poor.

Activated sludge treatment of calcium base sulfite liquors sewage mixtures produced B.O.D. reductions as high as 95 per cent. Very little color removal was affected.

In the course of these experiments parallel tests using bicarbonate water and bicarbonate water supplemented with ammonium salts and phosphate, showed the desirability of using the latter on waste of this type. Bicarbonate water gave low results due to lack of enough mineral elements to satisfy normal biological requirements. The slowing down of B.O.D. removal which was found when greater concentrations of waste sulfite liquor were treated by the activated sludge process is attributed to the same limiting factors which inhibit biochemical oxidation.

E. HURWITZ

BIOCHEMICAL OXIDATION IN ACID WATER CONTAINING SEWAGE

BY C. C. RUCHHOFT, M. B. ETTINGER AND W. W. WALKER

Ind. and Eng. Chemistry, **32**, 1394 (Oct., 1940)

Biological oxidations take place in regular oxygen sag curves in acid waters. Laboratory studies of these processes of self-purification were made in water containing 100 to 1,000 p.p.m. of free sulfuric acid. The purification process is characterized by a lag phase and period of rapid oxidation followed by a period in which further purification is very slow.

The biological character of the purification process was confirmed by experiments which indicated (1) that purification does not take place if the acid sewage is heat sterilized and sterility maintained, (2) that seeding acid samples with old acid sewage shortens the lag period very considerably, and (3) the presence of large numbers of viable organisms in the acid sewage undergoing purification.

The rate of de-oxygenation by acid sewage at low pH (2.7) is rapid after recovery from the lag period but the extent of de-oxygenation was only about 65.5 per cent of that observed in the normal biological pH range (7.0–8.0). These studies suggest that self-purification in streams carrying large amounts of acid (pH 2.0 to 3.0) is largely the result of biochemical reaction which is being carried on by a limited number of biological species. The absence of plankton necessary for complete biological flora is particularly noted.

E. HURWITZ

DETERMINATION OF BIOCHEMICAL OXYGEN DEMAND AND DISSOLVED OXYGEN OF RIVER MUD SUSPENSIONS

BY C. C. RUCHHOFT AND ALLEN MOORE

Ind. and Eng. Chemistry, Anal. Edition, **12**, 711 (Dec., 1940)

Studies of river mud suspensions has shown that the so-called immediate demand is not a true measure of the chemical demand but is largely an apparent loss due to failure of the analytical methods employed.

The determination of the initial dissolved oxygen of river mud suspensions indicated that the short Winkler method gave results from 8.47 to 74.7 per cent lower than the calculated initial, depending on the dilution examined. The alkaline hypochlorite results were from 5.84 to 52.8 per cent lower. When the suspended solids were removed by centrifuging, the initial D.O. results were only 1.26 to 15.7 per cent lower than the calculated. Finally in samples flocculated with alum and settled, the results checked in the highest dilution and were only from 4.35 to 14.1 per cent lower than the calculated in the others. Dilutions of mud were from 1/250 to 1/4000.

Another series of experiments showed that the larger part of this apparent loss in D.O. occurred in the acidification stage of the various procedures of D.O. determination. Results obtained in a comparative study of procedures are given in the table:

Results of Comparative Study of D.O. Procedures

(On 1/500 Dilution of River Mud)

Method	Method Rating	Number of Comparative Observations*	Initial D.O. (Calc.)	D.O. Found by Method Studied	Per Cent of Calc. Initial Found by Method
Rideal-Stewart	7	4	8.39	5.57	66.39
Short Winkler	6	6	8.65	5.76	66.59
Alk. Hypochlorite	5	5	8.12	6.95	85.59
Centrifuge	4	8	8.30	7.46	89.87
Alk. Hypochlorite plus Alum Flocculation	3	4	8.55	8.00	93.50
Alum Flocculation	2	9	8.29	7.76	93.60
Iodine plus Alum Flocculation	1	4	8.60	8.13	94.50

* Observations made in triplicate.

The iodine method consists in treating the sample with a slight excess of iodine, allowing it to stand 3 or 4 minutes, carefully neutralizing excess iodine, and flocculating with alum.

On the basis of results this method rated first. However on the basis of ease of manipulation and reliability the plain alum flocculation method is preferred.

Other tests indicated that the ordinary method for determining oxygen depletions in river muds gave fallacious results (1) because it does not include the apparent immediate depletion which is largely an interference and not a depletion and (2) the final D.O. after incubation are low due to interference. Also it was demonstrated in other tests that quiescent incubation gave low results.

It is recommended that the following steps be observed in determinations of B.O.D. on river mud:

(1) Calculation of initial D.O.
(2) Maintenance of solids in suspension by continuous rotation.
(3) Determination of dissolved oxygen upon rotated incubated samples after clarification with alum.

Flocculation is accomplished by treating the suspension in a liter bottle with 10 ml. of 10 per cent alum solution followed by one or two ml. of conc. sodium hydroxide solution. The stopper is inserted and the bottle twirled gently. The alum floc is allowed to settle, the clear supernatant siphoned into D.O. bottles and the short Winkler procedure applied. All the usual precautions must be taken to avoid introducing air into the sample.

E. Hurwitz

HESPELER'S NEW SEWAGE TREATMENT WORKS

By W. B. Redfern

The Canadian Engineer (Water and Sewage), **78**, 9, No. 8 (Aug., 1940)

A sewage treatment plant and a system of sewers is under construction for the town of Hespeler, Ontario. Hespeler is a town of 3,000 population located on the River Speed. A large woolen mill is the basic industry of the community. The total cost of the work will be about $105,000.

The sewers are for sanitary service only and are of vitrified clay pipe varying from 8 to 18 in. in diameter, aggregating 9 miles of length.

The topography is such that the sewage from 80 per cent of the area will flow to the plant by gravity. The balance of the sewage, from a small area south of the river, will be pumped in an underground pumping station. Two 125 g.p.m. pumps are provided. They will be automatic in operation.

The treatment works will include sedimentation tanks for year round use, and intermittent sand filters for secondary treatment during the hot summer months.

Two settling basins are provided, each 21 ft. wide by 36½ ft. long, with the bottom sloping toward the outlet end. The depth varies from 6 to 8 ft. Supernatant liquor passes over weirs to a secondary chamber common to the two basins, thence to an outlet chamber. An 18 in. line is provided between the outlet chamber and the sand filters. No sludge removal mechanisms are provided; a pair of 12 in. cast iron pipes, connecting each basin with the outlet chamber, will enable cleaning of the basins.

There are to be six filter beds, each 100 ft. square. Sand depths varying from 2¾ to 3¼ ft. will be used; conforming with the slope of the underdrains. The drains are on 25 ft. centers; in trenches 14 in. deep below the bottom of the sand. They are 6 in. in diameter, laid on cedar planks and covered with 1 in. stone, over which is placed a 3 in. layer of ½ in stone.

The collecting system of sewers is being installed with a frontage tax of 9 cents per foot per year on abutting property. Debentures for the treatment plant bearing interest at 3½ per cent, maturing in 15 years, were sold slightly above par. A 2 mill addition to the general tax rate will be required to meet debenture interest, repayment charges, and operating costs. Private drain connections will be paid for by the owners of the property. The cost will be about one dollar per foot for ordinary excavation.

T. L. Herrick

CERTIFICATION IN ONTARIO BEING FAVORABLY RECEIVED

By A. E. Berry

The Canadian Engineer (Water and Sewage), **78**, 20, No. 9 (Sept., 1940)

Skilled operators are necessary for expensive water purification plants and sewage treatment works on which large sums have been spent. This is obvious to designers of treatment works and to others familiar with the technical aspects of the work. Those who make the appointments are frequently not in a position to judge the technical qualifications of an applicant. Some standard requirement would be desirable; even a voluntary scheme of classification would be an improvement.

In Ontario, legislation has been recently passed setting forth standards for medical health officers and local sanitary inspectors. Steps are being taken in many of the states of the United States to ensure, by various methods, the proper qualifications of plant operators. There is no hard or fast rule being adapted but each has the same objective, irrespective of the type of certificate or license issued, or the method of training and the background of the organization passing on the qualifications.

The Canadian Section of the American Water Works Association has shown an interest in the qualifications of water plant operators. A committee recommended that action be taken by provincial departments of health to bring into operation the necessary steps for training operators.

In some places legislation has been provided which makes it mandatory that the operator be properly qualified; others adapt the voluntary scheme. For a start the latter has a wider appeal. In setting up a scheme for qualification of operators it is necessary to determine whether certificates be graded to suit the size and complications of the treatment works or whether only one grade should be used. It is indicated that more than one grade is desirable.

The project raises the problem of training. Should the operator secure this by experience in a plant or should special courses be provided to assist prospective operators, as well as those who have been engaged in the work for some time? The latter is now a requirement for newly appointed health officers in Ontario. It brings an opportunity for increasing the operators knowledge on subjects not readily acquired by experience in a plant.

All of these various items are matters for study in the proposal which has been receiving the attention of the Department of Health of Ontario.

T. L. HERRICK

BARRIE SEWERAGE WORKS

By G. GRAHAM REID

The Canadian Engineer (*Water and Sewage*), **78**, 7, No. 9 (Sept., 1940)

The town of Barrie, Ontario, was sewered on the separate plan during the period from 1894 to 1928. A considerable quantity of roof and ground water has been admitted from time to time so that it is now difficult to anticipate the flow from any sewer or any district. It is practically impossible to separate this storm water from the sanitary flow without knowledge of its exact source.

To relieve flooding, outlets into Kempenfeldt Bay were built at various points in the north part of the town.

An interceptor was built to carry the sewage to the treatment works in the southern part of the town. This flow is pumped at the works, while flows from the southern part pass to the works by gravity.

The interceptor was designed to provide cleansing velocities of from 3 to 4 ft. per second. For the greater part of the distance an asbestos-bonded asphalt-coated corrugated-iron pipe with paved invert was used. A velocity well above that anticipated has been obtained. In a great part of the distance the location was in a marsh, necessitating the use of piles for support. At 10 ft. intervals a single creosoted pile was used; each pile capped by a 6 in. by 8 in. creosoted block, with the top surface sawed to fit the pipe. The pipe was secured in place by means of 2 in. bands spiked to the blocks. For a great part of the length it was necessary to drive piles from 40 to 50 ft. in length. No deflection from line or grade has been noted to date, although in places it is under 14 ft. of sand backfill.

The remainder of the sewer and connections were constructed of vitrified double strength tile.

At the pumping station the sewage from the north interceptor, and the bottom part of the flow from the southern part of the town, first passes through a grit chamber and bar screen. Both are cleaned mechanically; the bucket teeth cleaning the bar screen and elevating grit and screenings to the ground level. A timer is provided so that one bucket will make a pass through the grit chamber and over the screen at any desired interval, or steadily if desired.

From this combined screen and grit chamber the sewage flows to the wet well, from which it is pumped by two horizontal pumps. One pump is rated at 1200 Imp. gal. per min. at 18 ft. head, and the other at 3600 g.p.m. at 17½ ft. head. The pumps are started and stopped by an automatic float control.

The discharge from the pumps, together with the flow not pumped, flows to two settling tanks provided with sludge removal equipment. The clarified effluent passes to a third similarly equipped tank which also serves as a chlorine contact tank. The effluent from this tank passes directly to Kempenfeldt Bay.

The outfall sewer is 470 ft. long and is laid on the bottom of the bay. It was constructed of 30 in. asbestos-bonded corrugated-iron pipe. The line was laid in the winter, the pipe being coupled together on the ice and submerged through a channel cut for it. The line was stabilized by piling rock around it at 20 ft. intervals.

Sludge lines were installed from the settling tanks to the sludge pump, located in the pumping station, and to the old sedimentation tank as well. This tank has been floored in the meantime to serve as a sludge storage chamber. One section of the tank may be equipped as a digestion chamber and the other utilized for separation of grease. It is expected that the sludge will be disposed of by tanking directly to the land, the nature of which is sandy. No arrangement has been made as yet to dispose of the grease but, as this is largely contributed by the pork packing industry, it is hoped that it may be prevented to some extent from reaching the plant.

The total cost of the intercepting sewer, right-of-way, connections and alterations to the old system was $65,000. The total cost of the pumping station and sewage treatment plant was $60,000.

T. L. HERRICK

DETERMINATION OF THE PERFORMANCE OF THE KESSENER UNITS

BY DENNIS DICKINSON

J. and Proc. Inst. Sewage Purification, Part II, 1939, p. 325–333

Laboratory methods used to determine the improvement in the sewage treatment plant at Stockport, England, after the installation of two Kessener aeration units are described. There is little difficulty in measuring the purification of sewage by activated sludge but it is a very different matter to estimate quantitatively the improvement in activated sludge brought about by reactivation. The author's method of the use of methylene blue for the determination of sludge condition is only qualitative. Therefore, other methods were tried. First, short time (½ hour) B.O.D. as a measure of sludge activity was used. There was considerable variation in B.O.D. values but little connection with purification efficiency. Reactivation brought about only a small improvement in the sludge as determined by the decrease in the ½ hour B.O.D. It is suggested that the effect of reactivation is cumulative and that it is not possible to feed a poor sludge to the reactivation unit and draw out a good sludge. The short time B.O.D. test was not considered of real value for the estimation of sludge condition. The determination of dissolved oxygen showed that reactivated sludge contained about 0.5 p.p.m. of D.O. There is very little difference between the sludge index of returned sludge and that of the corresponding reactivated sludge. Sludge density increased, however, since the Kessener units were started .

The sorption of various irreducible dyes was investigated as a possible measure for the condition of activated sludge. Colored positive ions were adsorbed strongly and the amount adsorbed was greater with reactivated sludge than return sludge as would be expected. But it did not follow that the better the sorption the better was the condition of the sludge. Thus there was some other factor besides the area of free surfaces. Support was given therefore to the suggestion of Ingols that the enzymes present in activated sludge might exert a controlling influence on the adsorption of solutes.

Positive colored ions of dyestuffs were adsorbed according to the Freundlich equation. The amount adsorbed varied with the sludge and the same sample of sludge was found to adsorb different equivalent weights of structurally similar dyestuffs. The fundamental enzyme equilibrium is represented by $[(Xo)(e)/Xr] = k$ where (Xo) and Xr represent the oxidized and reduced forms of an enzyme and (e) the concentration of free electrons. It would appear that the higher $(Xo)/(Xr)$ ratio the less a dyestuff will be adsorbed. On this basis a method is worked out by means of which return sludge can be distinguished from reactivated sludge. The method is based on the assumption that return sludge contains adsorbed unoxidized matter which is removed by reactivation. When a sample of return sludge is left to stand in a full bottle it decolorizes more methylene green than a sample tested immediately while a reactivated sludge does not show such a difference in the amount of dye decolorized between fresh and stale samples.

Other interesting points have been obtained from these studies. For instance, during a dry week there is a gradual increase from Monday to Friday in the demand for methylene green corresponding generally with a falling off in the quality of final effluent.

H. HEUKELEKIAN

EXPERIMENTS ON THE MANURIAL VALUE OF SEWAGE SLUDGE FROM SEPTIC TANKS

BY H. T. CRANFIELD

Empire Journal of Experimental Agriculture, 7, 319 (No. 28), (Oct., 1939)

The analysis of sludge from lagoons following septic tanks from certain Midland towns in England not exceeding a population of 50,000 is given as follows:

Moisture	50–80%
Organic matter	10–30%
Total nitrogen	0.5 –1.0%
Phosphoric acid	0.1 –0.5%
Potash	0.03–0.3%
Ether soluble matter	1–9%

The material from lagoons was stored in 50-ton heaps for a period of two years with the following results:

	Moisture %	On Dry Matter Basis	
		Organic Matter %	Total N %
After 5 months	67.6	56.2	2.0
After 10 months	41.5	48.4	2.6
After 16 months	51.5	43.7	1.73
After 23 months	54.4	43.4	2.55

Thus the sticky wet material from the lagoon was converted into a workable state. At the same time the loss of organic matter was not serious. However, longer periods of storage may cause serious losses as indicated by the following results:

	On Dry Matter Basis	
	Organic Matter	Total N
From an Old Dump 6 Years Old	30.9	1.25
From a Heap 6 Months Old	48.3	2.42

The following treatment and crop yields were obtained from field experiments laid on a sandy loam soil.

	Yield of Potatoes, Unit per Acre
Plot 1, Manure 15 tons; artificial fertilizers 10 cwt	133.1
Plot 2, Sewage sludge 15 tons; artificial fertilizers 10 cwt	134.6
Plot 3, Artificial fertilizers 10 cwt	115.4
Plot 4, Control	98.5

From a number of such experiments with different soils the conclusion was drawn that under favorable conditions sewage sludge may be as effective as manure. If conditions are adverse militating against rapid decomposition, manure has a distinct ad-

vantage over sludge. However, under reasonable normal climatic conditions sludge can be used as a substitute for manure and its use would be justified in increased yield of crops such as potatoes. To obtain good results dressings of artificial fertilizers must also be applied. For market garden crops such as carrots, onions, beet and peas it is suggested that the sludge should be dug in, some months before sowing and the ground dug over a second time.

With potatoes the material can be spread in the bottom of the trench. Ample moisture is necessary for decomposition. In no case was any deleterious effect due to the presence of greasy matter noticed. The heaping of sludge for a year or two or even composting with soil materially improves the utilization of this manure by producing a more friable material which can be distributed more evenly. On certain soils an appreciable residual manurial value may accrue in favor of the second year's crop.

H. HEUKELEKIAN

THE SYSTEM ACTIVATED SLUDGE–OXYGENATED WATER. PART V. CHANGES IN OXIDATION—REDUCTION POTENTIAL WITHIN THE SLUDGE FLOC

BY DENNIS DICKINSON

J. of the Society of Chemical Industry, 59, 257–258 (No. 11), (Nov., 1940)

A large floc of activated sludge was allowed to grow on the surface of a platinum electrode by placing the electrode under a slow stream of sewage trickling over the surface of the platinum. The floc grew from nuclei and covered the surface of the platinum in three to four weeks. The bio-electrode thus obtained consisted of a large floc with a platinum core. When once prepared an electrode of this type can be kept indefinitely provided it is kept constantly wet and fed with aerated sewage at frequent intervals. The bio-electrode is immersed in a sewage solution and connected to one terminal of a sensitive galvanometer. A bright platinum electrode similar in all respects to the core of the bio-electrode is immersed in the same solution and connected through a key to the other terminal of the galvanometer. When the circuit was completed the galvanometer needle deflected. By measuring the magnitude of the immediate deflection of the galvanometer it was possible to follow decided changes in the e.m.f. under various conditions. The different bio-electrodes prepared did not agree quantitatively but all showed the same general behavior when aerated with sewage or with solutions of various organic compounds.

To follow the potential change within the sludge floc during aeration with sewage the bio-electrode and bright platinum electrode were passed through the stopper of a straight-sided separatory funnel of 50 ml. capacity. A glass tube was passed through the stopper and was connected to an aspirator pump, air being thus drawn upwards through the solution in the funnel. Sewage or organic solutions placed in the funnel were thus purified by the bio-electrode. In general there was a relatively rapid fall in the potential of the bio-electrode with respect to the bright platinum electrode after which a fairly constant level was maintained over a long period. This was followed by a slow rise up to the initial potential level and sometimes beyond it. It was necessary to prolong the aeration for some time after the complete clarification of the sewage in order to attain the initial potential level. The bio-electrode after long reactivation was found to be slightly positive to the platinum electrode when both were immersed in settled sewage but it became negative rapidly. Prolonged feeding of the bio-electrode with glucose, which resulted in a bulky condition of the sludge, had the effect of increasing the potential. When the electrode coated with this type of sludge was immersed in sewage and aerated, instead of the usual fall in potential there was an initial rise and the potential did not begin to fall until after two hours' aeration.

The results confirm the existence of a potential difference between the center of an activated sludge floc and a sewage solution. This potential difference is due largely to the oxidation-reduction potential of the sludge enzymes. The author suggests that the adsorption or surface concentration of sewage materials in activated sludge floc is not adsorption in the strict physio-chemical sense.

H. HEUKELEKIAN

BIOCHEMICAL STUDIES ON THE PURIFICATION MECHANISM OF ACTIVATED SLUDGE

BY MASAZO WATANABE

Mitteilungen aus der Medizinschen Akademie au Kioto, 30, 861–1008 (No. 3), (1940)

I. STUDIES ON THE BIOLOGICAL ACTION OF ACTIVATED SLUDGE

The author approaches the biological problem from the standpoint of the decomposition of pure substances such as carbohydrates, proteins and fats. The carbohydrates studied included mono-, di- and polysaccharides. 100 ml. of 1 per cent sugar solution was added to 200 ml. of activated sludge, the pH values adjusted with phosphate buffers to 4.5, 5.7, 7.0 and 8.2 and shaken for 8 hours at 37° C. At intervals the amount of sugar remaining was determined. The disappearance of the sugars at different pH values on aeration with activated sludge was also studied. The following table summarizes the results obtained on aeration of the carbohydrate with activated sludge for a period of 8 hours.

	Glucose	Glycogen	Starch	Maltose	Mannose	Lactose	Laevulose	Arabinose	Galactose	Xylose
Decomposition, per cent..	95.6	94.9	94.7	87.6	84.7	73.3	69.9	29.3	28.9	11.5
Optimum pH.....	7.0	8.2	8.2	7.0	7.0	7.0	7.0	7.0	7.0	7.0

The rate of disappearance of the carbohydrates was higher with aeration than without aeration. The effect of temperature on the rate of disappearance of carbohydrates was as it was to be expected—a higher rate of disappearance with higher temperature, up to 37° C.

The decomposition of nitrogenous materials by aeration with activated sludge was studied by adding 700 ml. of 0.1 per cent solution of these materials to 700 ml. of activated sludge and 700 ml. of borate buffer solution. The decomposition of the substances was followed at the end of 4 and 8 hours of aeration by determinations of organic nitrogen, oxygen consumed and B.O.D. The mixtures were adjusted to the following pH values initially: 2.2, 3.4, 4.6, 5.8, 7.0, 8.2, 9.4 and 10.6. Using the different yardsticks for the determination of the effect of pH on the rate of decomposition of nitrogenous materials the following results were obtained:

	Optimum pH
Albumin	6.3–6.6
Peptone.....	7.1
Urea.....	6.6
Sewage.....	7.3

On either side of these pH values the rate of decomposition was materially retarded.

In a series of experiments to determine the optimum activated sludge concentration to be maintained, it was found that for the treatment of sewage a 30 per cent return (actual suspended solids concentrations not given) was the best. When the sewage was fortified with nitrogenous materials (nature and quantity not stated) the best results were obtained when higher sludge volumes were used.

Activated sludge digested at 37° C. for 48 hours, prior to aeration with sewage, removed nitrogenous materials at a much slower rate than fresh sludge.

For the study of the decomposition of oils by activated sludge olive oil was used. The rate of disappearance of the oil was determined by drying the sludge and extracting the residue with ether. The rate of disappearance of the oil was studied at pH values of 4.5, 6.0, 7.0 and 8.0. After 8 hours' aeration the following percentages of the oil were decomposed:

$$\text{pH } 4.5 = 7.4\%;\ \text{pH } 6.0 = 11.3\%;\ \text{pH } 7.0 = 15.5\%;\ \text{pH } 8.0 = 12.8\%.$$

In the unaerated series the rate of decomposition was even lower. These rates are much lower than those observed for the other pure substances studied.

The author came to the conclusion from the lack of removal of any of these materials in sewage by heated activated sludge that these substances are destroyed by the organisms in the activated sludge. In addition to this bacterial action the rôle played by enzymes and adsorption is pointed out.

II. Studies on the Enzymic Action of Activated Sludge

After contrasting the views held by various investigators as to the relative importance of living organisms as against purely enzymic reactions the author came to the conclusion that further work was necessary to establish the importance of pure enzymic reactions. An attempt was made to purify the enzymes of activated sludge. It was found that the cell-free filtrate of activated sludge had a fermenting ability. The bacteria-free filtrates were obtained by filtering activated sludge through Berkfeld filter N and L. To contrast the action of the bacteria-free filtrate with the enzymic action of the sludge floc, activated sludge was treated with toluene to inhibit bacterial action, although this treatment did not eliminate entirely all the bacteria. The diastatic, proteolytic and lipolytic action of the filtrate and toluene treated sludge was studied by introducing these materials into suitable substrates with varying pH values and incubating under toluene for a period of 48 hours at 37° C. At the end of different intervals during this period the hydrolytic products were determined. It was found that the optimum pH for diastatic activity was 6.5. The diastatic activity of bacteria-free activated sludge filtrate was much lower than that of the floc in which bacterial activity was inhibited.

Tryptic and peptic enzymes were studied by digesting casein under toluene at the optimum pH values of these individual enzymes and determining the amino acids produced. Tryptic activity of activated sludge was three times higher than the peptic activity. Again the proteolytic activity of sludge liquor was considerably less than that of the floc itself.

For lipolytic action the substrate used was monobutyrin adjusted to different pH values, the reaction taking place under toluene at 37° C. for 48 hours. The acidity produced as a result of hydrolysis was measured. The optimum pH for lipolytic action was found to be 6.5 and the action was again much lower with the sludge liquor than with the floc itself.

In order to isolate and separate the enzymes, bacteria-free sludge liquor was shaken with kaolin, Fuller's earth and animal charcoal, and the liquor separated after centrifuging. The adsorbed enzyme was then separated from the adsorbent and the clear liquor separated used as the enzyme source. The liquor separated after shaking with the absorbent, containing the non-absorbed enzymes was also tested. It was found that Fuller's earth and animal charcoal were better adsorbents for activated sludge diastase than kaolin. The portion of enzyme not adsorbed by kaolin showed a greater diastatic activity than the adsorbed fraction. This relationship was reversed in the case of Fuller's earth and animal charcoal in that the adsorbed fraction was more active than the non-adsorbed fraction. In comparison with the diastase activity of the original sludge liquor the activity of the fraction adsorbed by Fuller's earth and animal charcoal was materially higher.

Aeration of the sludge with or without the addition of starch increased the diastatic activity, the increase in the former case being higher. Aeration which is thus found to be beneficial for enzyme activity is also beneficial for the development of aerobic micro-

organisms in activated sludge. The optimum pH for the hydrolytic enzymes is around 6.5, whereas the pH value of sludge mixture is around 7.0–7.4. Therefore the enzymes of activated sludge do not act at their optimum pH value. However it is difficult to separate the activity of the enzymes from the microbiological activity.

III. Studies on the Adsorption of Activated Sludge

The sludge for these studies was dried, pulverized and passed through 0.35 mm. sieve and was uniform in composition for all the experiments. Raw activated sludge was also used which naturally was not the same in composition for all the tests made. About 10 per cent of glucose solution (0.2–0.3%) was adsorbed by dry pulverized activated sludge and the adsorption was complete in 15 minutes of shaking. The sugars were adsorbed in the following order: Glucose > Laevulose > Maltose. The adsorption of these materials by sludge behaved according to the Freundlich equation. Iodine was similarly adsorbed but to a greater extent than the sugar. The organic acids were adsorbed in the following order: Valerianic acid > butyric acid > proprionic acid > acetic acid > formic acid. In other words the adsorption was greater the higher the molecular weight. The adsorption exponent of 1/N varied between 0.175 and 0.874 for the different compounds tested. Studies on the adsorption by fresh activated sludge were conducted with materials that could not easily be utilized biologically such as iodine, oxalic acid, lactic acid, formic acid, acetic acid, proprionic acid, butyric acid and varlerianic acid. The adsorption by the fresh sludge was lower than by the dried sludge. The adsorption of a number of different dyes by fresh activated sludge was also studied. The adsorption of the different dyes varied considerably but again the Freundlich equation could be applied. The adsorption of the dyes were of the following order: methylene blue B > Phosphine > Auramine > Crystal violet > Benzobrown B > Japanol Dark green > Seiden ponceau > Benzopurpurene B > Rhodamine B > Congo red.

A comparison was made of the adsorbing power of kaolin, Fuller's earth and animal charcoal with that of fresh activated sludge for the removal of impurities from sewage.

These materials were added to heated sewage (to kill bacteria) shaken and centrifuged. The oxygen consumed determinations were made on the centrifuged liquor. Kaolin did not give any removal; adsorbing power of Fuller's earth for sewage impurities was lower than that of activated sludge and animal charcoal, the latter giving the highest removal. Biological activity in the activated sludge is not precluded. The contact period with the adsorbing materials was 2 hours.

Thus activated sludge has a noteworthy adsorption capacity. It is suggested that soluble organic matter of sewage is first adsorbed by the sludge and subsequently oxidized by the microorganisms. Even non-assimilable materials are thus adsorbed as was shown by the adsorption of the iodine. Adsorption and biological activity are interdependent. The purification mechanism of activated sludge depends upon (1) biological, (2) enzymatic and (3) adsorption reactions.

IV. Polarographic Studies on Specific Ash Constituents of Activated Sludge

The ash constituents of activated sludge were analyzed by means of a polarograph. The following results were obtained:

Cu	0.00448%	Zn	1.2146%
Lead	0.4780%	Al	0.0276%
Fe	1.5680%	Mn	0.0039%
Cd	0.0055%	Na	0.6100%
K	0.0130%	Mg	1.0060%
Ca	0.4900%	Si	19.4830%
P	1.2070%		

The author believes that small traces of some of these elements are of considerable importance in the activated sludge process.

H. Heukelekian

SECOND ANNUAL CONVENTION
FEDERATION OF SEWAGE WORKS ASSOCIATIONS

NEW YORK CITY, OCT. 9–11, 1941

The Second Annual Convention of the Federation of Sewage Works Associations will be held in New York City on October 9, 10 and 11, 1941. Headquarters will be at the Hotel Pennsylvania. The Convention will be held in conjunction with the Fall Meeting of the New York State Sewage Works Association.

The program is planned to appeal to operators and an entire session will be devoted to a symposium on operating problems. The operation keynote will be further emphasized by a "sunrise breakfast" and round table discussion on topics of particular interest to sewage works operators. There will also be a session devoted to the presentation of papers of general interest, or of research type, by outstanding leaders from all parts of the country.

Exhibits of new sewerage and sewage equipment and materials will be shown at the Hotel Pennsylvania. The number of exhibitors is expected to exceed the total of fifty-five present at the Chicago convention.

An inspection trip to one or more of New York's new sewage treatment works is planned. Social events include a smoker and the annual banquet, with entertainment and dancing. The ladies will be welcome and are urged to attend.

Convention committees are as follows:

General Convention Management Committee

A. S. BEDELL, *Chairman*
C. A. EMERSON, JR.
CLINTON INGLEE
L. L. LUTHER
W. J. ORCHARD
J. HERMAN SMITH

Sub-Committee Chairmen

Finance.....W. J. ORCHARD
Entertainment.....CLINTON INGLEE
Manufacturers' Exhibits.....J. HERMAN SMITH
Ladies' Entertainment.....MRS. C. A. EMERSON, *Honorary Chairman*
MRS. KARL MANN, *Chairman*
Local Host.....RICHARD H. GOULD
Inspection Trip.....W. DONALDSON
Publicity and Attendance.....MORRIS M. COHN
Program.....F. W. GILCREAS

Details of the technical and social program will be published in our July issue. The September issue is to be a special Convention Number, devoted exclusively to operators' papers, news about the convention, facts about new equipment, and in general enthusiasm for the coming convention.